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Upper Chehalis River Basin Temperature
Total Maximum Daily Load

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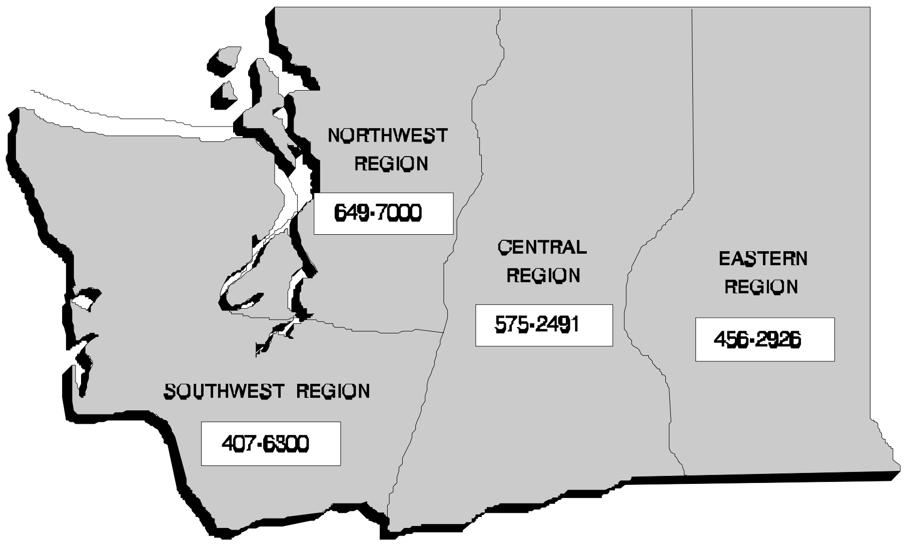

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Upper Chehalis River Basin Temperature Total Maximum Daily Load

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Introduction

Section 303(d) of the federal Clean Water Act mandates that the State 'establish analyses called Total Maximum Daily Loads (TMDLs) for surface waters that do not meet standards after application of technology-based pollution controls. The U.S. Environmental Protection Agency (EPA) has promulgated new regulations (40 CFR 130) and developed guidance, (EPA; 1991) for establishing TMDLs.

Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses, such as cold water biota and drinking water supply, and criteria, both numeric and narrative; to achieve those uses. When a lake, river or stream fails to meet water quality standards after application of required technology-based controls, the Clean Water Act requires the state-to place the water body on a list of "impaired" water bodies and prepare a TMDL.

The goal of a TMDL (sometimes called a Water Cleanup Plan) is to ensure the impaired water will attain water quality standards. It includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant which can be discharged to the water body and still meet standards, the **loading capacity**,. and allocates that load among the various sources. If the pollutant comes from a discrete source (referred to as a **point source**) such as an industrial facility's discharge pipe, that facility's share of the loading capacity is called a **wasteload allocation**. If it comes from a diffuse source (referred to as a **nonpoint** source) such as a farm, that facility's share is called a **load allocation**.

The TMDL must also consider seasonal variations and include a **margin of safety** that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. The sum of the individual allocations and the margin of safety must be equal to or less than the loading capacity.

The Upper Chehalis River Basin TMDL, developed by the Washington State Department of Ecology, is being established for heat caused by solar radiation. Heat is considered a pollutant under Section 502(6) of the Clean Water Act. Heat generated by the amount of solar radiation from sunlight reaching the stream provides energy to raise water temperatures. This TMDL is designed to address impairments due to surface water temperature increases on nine water quality-limited streams (representing 19 segments) located in the watershed and provide goals for protection of all remaining streams. Streamside shade is used as a surrogate for water temperature increases, as allowed per federal regulations. A decrease in shade increases incoming solar radiation and the resultant heat transfer to the stream. A more complete description of the factors influencing stream system temperatures appears in Appendix E.

The five elements of a TMDL as required by federal statute and regulation are summarized below:

Loading Capacity: The loading capacity of solar radiation is based on the shade levels in the riparian condor needed to meet state water quality standards for temperature. Shade levels were determined by adjusting the vegetative shade values in the model such that the temperature standard was just met at each listed segment. The resulting loading capacities for streams in the Chehalis River Basin TMDL are presented in units of percent vegetative shade. (Table 11).

For three streams (South Fork Chehalis River, Newaukum River, Black River) the amount of achievable shade alone was not sufficient to meet temperature standar4s. Targets for a reduced width-to-depth ratio were also established to meet temperature standards. Therefore, the loading capacity for these streams assumes that stable channels are formed by managing the ., processes affecting them.

Load Allocations: Load allocations of riparian shade are established for 13 stream reaches. In addition to the defined numeric load allocations for shade, there are several assumptions that must be met if temperature standards are to be achieved. These assumptions are considered part of the load allocation, since changing them would affect the load allocation and likely result in temperature standards riot being met.

Wasteload Allocation: Discharge temperatures for 4 point source inputs are established at the level which would not increase the temperature of the receiving stream during critical conditions.

Margin of Safety: The analysis provides the required margin of safety by using several conservative assumptions in the modeling, including extreme summer conditions setting topographic shade to zero for most reaches, using the lowest basin latitude for all reaches, and applying the 10-year, 7-day low flow.

Seasonal Variation: A review of monitoring data collected in the Upper Ch ehalis River Basin shows that most temperature measurements that exceed the criteria occur in June and July. Since it is not possible to change allocations of shade over a season, they were set based on this critical summer period.

Background

The Upper Chehalis River Basin covers 1,293 square miles, extending from the g Black Hills south of Olympia to the Willapa Hills (Figure 1). This large watershed is identified in State rule as Water Resource Inventory Area 23. The basin area covers 5 counties: Lewis (60%), Thurston (24%), Grays Harbor (11 %), Pacific (4%),. and Cowlitz (1 %). The Chehalis Tribal Reservation is on the northwestern area of the basin along the mainstem Chehalis River The river passes through the two biggest cities in the basin, Centralia with a population of over 12,000 and Chehalis with a population of about 6,500.

Land use in the basin is predominated by forested areas (83%), followed by agricultural lands (14%) and urban areas (2%). Average annual precipitation is 57 inches, and ranges from 30 inches near the City of Chehalis to 120 inches near the headwaters of the Chehalis River in the Willapa Hills. Upper Chehalis Riser Basin Temperature TMDL

Major tributaries of the Upper Chehalis River are the South Fork Chehalis River, the Newaukum River, the Skookumchuck River, and the Black River. Numerous creeks feed the mainstem, of which the largest are Elk, Bunker, Steams, Dillenbaugh, Salzer, Rock, and Cedar Creeks. The headwaters of the mainstem and South Fork Chehalis rivers lie in the eastern Willapa Hills: the headwaters of the Newaukum and Skookumchuck Rivers flow from the Bald Hills, a western spur of the Cascade mountain range; and the Black River and Cedar Creek drain from the Black Hills (Figure 1).

A temperature TMDL for the Upper Chehalis River Basin was submitted to EPA for approval in January 1996. EPA determined that the TMDL was incomplete because cumulative effects were not assessed. Subsequent efforts by Ecology to complete the TMDL proved unacceptable (Appendix B). As part of the TMDL lawsuit settlement agreement, Ecology agreed to revise and resubmit the TMDL by June 1999. To address cumulative effects, the TMDL has been revised based on a stream network temperature model (SNTEMP) which assesses the cumulative effects of several factors, since the accumulated heat is routed through the major streams of the watershed (Theuer et al. 1984).

Heat generated by sunlight reaching the stream provides energy to raise water temperatures. Riparian vegetation reduces stream temperature by blocking the sunlight from reaching the stream. Human-caused activities which contribute to degraded riparian vegetation conditions in the Upper Chehalis River Basin area include agricultural activities, residential and urban development, and silvicultural activities. Two other factors that influence the distribution of heat are assessed: instream flow and channel morphology. Low flows may contribute to high temperatures by reducing the volume of water that can absorb incoming heat. Channel morphology may also influence heat distribution. With increased sediment loads, stream channels may become wider and shallower, allowing more thermal radiation to be absorbed by the water surface.

Applicable Criteria

Within The State of Washington, water quality standards are published pursuant to Chapter 90.48 of the Revised Code of Washington (RCW). Authority to adopt rules, regulations, and standards as are necessary to protect the environment is vested with the Department of Ecology. Under the federal Clean Water Act, the EPA Regional Administrator must approve the water quality standards adopted by the State (Section 303(c)(3)). Through adoption of these water quality standards, Washington has designated certain characteristic uses to be protected and the criteria necessary to protect these uses [Washington Administrative Code (WAC), Chapter 173-201A). These standards were last adopted in November 1997.

This TMDL is designed to address impairments of characteristic uses cause d by high temperatures. The characteristic uses designated for protection in Upper Chehalis River Basinstreams are as follows:

(i) "Water supply (domestic, industrial, agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

> *Salmonid migration, rearing, spawning, and harvesting.*
> *Other fish migration, rearing, spawning, and harvesting.*
> *Clam and mussel rearing, spawning, and harvesting.*
> *Crayfish rearing, spawning, and harvesting. (iv) Wildlife habitat.*

(iv) Wildlife habitat.

(v) Recreation (primary contact recreation, sport fishing, boating and

(vi) Commerce and navigation."

[WAC 173-201A-030(2)]

The water quality standards describe criteria for temperature for the protection of characteristic uses. Listed streams in the Upper Chehalis River Basin are designated as Class A. Class A have assigned temperature criteria to protect the characteristic uses:

For Class A waters:

> *"Temperature shall not exceed 18.0°C... due to human activities When natural conditions exceed 18.0°C..., no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C."*
>
> *"Incremental increases resulting from nonpoint activities shall not exceed 2.8°C "*

[WAC 173-201A-030(2)(c)(iv)]

Water Quality and Resource Impairments

As a result of measurements that show temperature criteria are exceeded, nine streams (representing 19 segments) are included on the Washington 1998 Section 303(d) list (Table 1).

Table 1. Upper Chehalis River Basin 1998 Section 303(d) Listed Segments

Stream Name	Segment Location (Township-Range Section)
Black River E	15N-04W-OS
Chehalis River (mainstem)	13N-05W-12, 14N-02W-07, 14N-02W-18, 14N-02W-24, 14N-03W-12, 14N-03W-24, 14N-03W-25, 15N-03W-22, 16N-05W-36, 17N-05W-28
Chehalis River, South Fork	13N-04W-24
Dillenbaugh Creek	13N-02W-O5, 14N-02W-31
Lincoln Creek	1 SN-03 W-29
Newaukum River	14N-02W-31
Salzer Creek	14N-02W-19
Scatter Creek	1 SN-03 W-08
Skookumchuck River	14N-02W-07

Temperature data collected in the Upper Chehalis River Basin show a definite pattern of seasonal variation. Data collected by Ecology's Ambient Monitoring Program at 10 stations between October 1991 and September 1998 were compiled and descriptive statistics generated (Table 2). Most of the year, temperature criteria are met. The critical period for temperature in the Upper Chehalis River Basin is in the months of June and July.

Table 2. Temperature Statistics of the Upper Chehalis River Basin

Month	**Number of Samples**	**Mean Temperature (°C)**	**Median Temperature (°C)**	**Maximum Temperature (°C)**	**Samples over the Criteria (%)**
January	29	5.1	4:9	9.1	0%
February	29.	5.1	5.0	9.7	0%
March	29	8.3	8.2	11.3	0%
April	29	10.0	10.0	12.8	<0.1
May	29	14.1	14.5	18.1	17%
June	29	16.3	16.2	24.5	62%
July	29	18.9	18.5	22.2	24%
August	29	16.9	17.0	19.8	<0.1
September	29	13.6	13.6	18.4	0%
October	29	9.4	9.4	13.1	0%
November	29	7.2	7.4	10.1	0%
December	29	5.4	4.9	10.5	0%

The Upper Chehalis River Basin TMDL establishes goals for shade as a surrogate measure designed to meet water quality standards for temperature. Few data are readily available on the existing shade conditions in the basin. The most quantitative data on shade have been collected as part of watershed analyses (WAC 222-22) conducted on 4subbasins: Upper and Lower Skookumchuck, Stillman Creek and the Chehalis River headwaters. In addition, qualitative information on removal of riparian vegetation was collected as part of a basin-wide U.S. Fish and Wildlife Service study (Wampler, et al 1993). This study found over 30 vegetation has been lost or reduced (Table 3).

Table 3. Conditions of Riparian Vegetation Estimated for , the Upper Chehalis River Basin

Watershed	**Stream Miles Surveyed**	**Observed Riparian Degradation**			
		Vegetation Loss		**Reduced Tree Canopy**	
		Miles	Percent	Miles	Percent
Upper Chehalis River(Mainstem)	28	10.4	37%	6.7	24%
Gibson Creek	38	2.5	7%	2.2	6%
Rock Creek	53	6.4	12%	12.2	23%
Black River	88	26.1	30%	24.6	28%
Lincoln Creek	63	5.2	8%	24.6	39%
Scatter Creek	31	18.7	60%	16.3	53%
Skookumchuck River	110	70.2	64%	39.6	36%
China Creek	37	34.2	93%	23.0	62%
Newaukum	125	28.3	23%	50.4	40%
Stearns Creek	20	1.2	6.1%	18.0	90%
Scammon Creek	47	6.3	13%	29.2	62%
Chehalis River, South Fork	113	35.8	32%	47.9	42%
Elk Creek	43	11.6	27%	5.5	13%
Rock Creek	42	6.3	15%	13.6	32%
Overall Total	**838**	**263.1**	**31%**	**3.13.8**	**37%**

The Upper Chehalis River Basin TMDL addresses some fisheries concerns resulting from water temperature increases. Excessive summer water temperatures have reduced the quality of spawning and rearing habitat for salmonid fish in several Upper Chehalis River Basin streams. High temperatures harm salmonid fish.

The streams of the basin support substantial runs of anadromous fish and support commercial, sport, and tribal fisheries. An assessment by the State and tribes in 1992 showed al l species of salmonid stock (Chinook, Chum, Coho, and Steelhead) in the basin to be healthy (SASSI, 1993). However, since that assessment, the National Marine Fisheries Service has identified the Coho salmon as a candidate for listing as a Threatened and Endangered species under the federal Endangered Species Act (ESA). The final ESA listing assessment is expected m 1999. The original Chehalis River TMDL for dissolved oxygen was initiated due to a major fish kill that occurred on the Black River in 1989. (Pickett, 1997).

Modeling Approach

SNTEMp and SSSHADE are the models used to assess the effects of solar radiation, channel morphology and instream flow on temperature in stream reaches of the Upper Chehalis River watershed. SNTEMP, a stream temperature network model written by Theurer et. al. (1984), is currently supported by the U.S. Geological Survey. It is a mechanistic, one-dimensional, heat transport model that analyzes temperature conditions for a network of streams in stead state. The model was developed to help predict the consequences of manipulation of various factors influencing stream temperatures. SSSHADE is a stream-shading model that is used to provide input variables to the SNTEMP model. SSSHADE estimates stream shading from various riparian characteristics.

SNTEMP and SSSHADE require input data for 28 parameters and variables ranging from channel conditions to climate. Many of these kept constant for all model runs. Several others were varied to assess the impact of various factors. The following are a list of the model input parameters used.

Stream Network Geometry: The stream network was divided into numerous reaches based on location of significant tributaries and hydraulic characteristics. Tributary streams that are on the 1998 Section 303(d) list for temperature were modeled as branches to the network. Other significant tributaries were treated as point source inflows. The mainstem. Chehalis River was divided into 4 separate hydraulic reaches based on staff best professional judgement (Pickett, 1999). A schematic of the modeled stream network is shown in Figure 2.

Reach.Lengths: Derived from the Washington Department of Fisheries River Mile Index (WDF, 1975).

Latitude: Used 0.81158 radians (46.5*) for all reaches representing the lowest latitude of the study area. The most extreme value was selected as one element of the inherent margin of safety.

Elevation: Determined for each network stream node from the 7.5 minute GIS coverage derived from USGS and Forest Service digital elevation models.

Manning's n: Initially estimated for each reach in the range of 0.035 to 0.060 using channel and flow characteristics. Using knowledge of the stream characteristics, this parameter was adjusted within accepted ranges during model calibration, to approximate measured temperatures in the modeled reaches.

Width Coefficient and Exponent: These figures were derived from width and instream flow data collected by Pickett (I 994a&b). For each hydraulic reach of the mainstem Chehalis River, measured wetted width and flow data from a representative reach not impacted by bridge crossings were regressed into a power function. Likewise, data from the tributaries (excluding the Black River) were pooled to derive these parameters. The Black River parameters were figured separately from the other modeled tributaries to the mainstem Chehalis River.

Stream Shading: Information was determined from the output results of the SSSHADE model. For each modeled stream reach, the type of vegetation was determined by intersection of the Cream hydrology GIS coverage with the Washington Department of Natural Resources GIS coverage depicting canopy in 1991 derived from Landsat/TM satellite imagery. This intersection of G1S coverages resulted in a linear coverage estimating the adjacent canopy type for each Stream reach. The percentage of each canopy type was determined for each reach. The SSHADE model was run with applicable parameters for each reach-and canopy type. The Overall shade for the overall reach was determined by proportion of canopy type and the modeled shade results for each. The parameters and assumptions used in SSSHADE are described further flow, and the results are shown in the Appendix (Table A1).

Ground Temperature: 9.9°C was used. That was the mean annual air temperature from 1948 to 1998 measured at Olympia Airport, just north of the watershed.

Streambed Thermal Gradient: 1.65 joules/m2/sec/C was used. The model documentation recommended using that as the default value, in lieu of a measured value.

Time Period: For model calibration and validation, the conditions for the month of August were modeled. The SNTEMP model was run steady state for a 30 day averaging period (Julian days 213 to 243) to bound the watershed time of travel of 20 days determined by Pickett (1994a). The SSSHADE model was run for August 15d', representing the sun angle during the middle of the month.

Dust Coefficient: The value of 0.06 was used as the summer mean measured in a similar geographic region (TVA, 1972).

Ground Reflectivity: The value of 0.29 was measured from late summer vegetation with leaves law in water content (TVA, 1972).

Meteorology Station Latitude: 0.81978 radians represents the location of Olympia Airport.

Meteorology Station Elevation: 58 meters represents the location of Olympia Airport.

Mean Annual Air Temperature: 9.9°C was based on the average of daily maximum and minimum air temperatures collected from Olympia Airport between 1948 and 1993.

Mean Air Temperature for Calibration & Validation: 18.5°C and 18.2°C were derived from measured values at Olympia Airport from August 1991 and 1992, respectively.

Mean Wind Speed for Calibration & Validation: 2.6 meters/second and 2.7 metes/second were derived from measured values at Olympia Airport from August 1991 and 1992, respectively.

Mean Relative Humidity for Calibration & Validation: 72 percent and 67percent were derived from measured values at Olympia Airport from August 1991 and 1992, respectively. .

Percent Sunshine for Calibration & Validation: 100% assumed a cloudless day. The most extreme value was selected as one element of the inherent margin of safety.

Lateral Inflow Temperature: For many of the reaches, the mean annual air temperature measured at Olympia Airport between 1948 and 1993 (explained above) was used. This value is commonly used to approximate the temperature of the groundwater (Theuer et al. 1984). However, many of the modeled reaches may have a considerable percentage of surface water entering as lateral inflow through small ditches and streams. These lateral surface water inflows probably have a higher temperature than ground water. In contrast, groundwater in the headwater streams at higher elevations is likely to be cooler than the temperature measured at Olympia Airport. This parameter was adjusted in the calibration of the model to approximate measured temperatures in the modeled reaches.

Instream Flow for Calibration & Validation: For most reaches, modeled flows from Tables C3 and G I in Pickett (I 994a) were used. 'However, data from the USGS on 8/27 was used for the headwaters at Skookumchuck River Mile 6.5 since this location was not modeled by Pickett (I 994a). Also, data from Pickett (I 994b) was used for the Black River.

Instream Temperature for Calibration & Validation: For most river reaches, measured temperatures from Tables D I and F I in Pickett (I994a) were used. Also, data from Pickett (I994b) was used for the Black River. Since temperatures of the three wastewater treatment plant discharges were not measured, the maximum river temperature measured at the surface near the point of each discharge was used as the effluent temperature. Temperature values for the mainstem Chehalis River model nodes were compared to the first downstream station measured. Since the model is only one-dimensional, only surface temperatures were used where profile data were collected as one element of the inherent margin of safety. Due to a larger set of data available, the highest temperature measured in August was used for comparison to the 30-day steady state model runs. Values used for comparison to calibration and validation model runs are shown in the Appendix (Table A2).

Azimuth: For each modeled stream reach, the degrees representing the general bearing between the headwaters and the mouth (or beginning and end of the reach) were used.

Stream Width: For each modeled reach, the median stream wetted width was taken from measurements collected by Pickett (I 994a&b). These measured values were used for the modeled mainstem Chehalis River reaches. However, the widths of the tributaries were generally measured at the widest location on the stream, since they were collected near the mouth. These streams typically range from the widest part measured near the mouth to decreasingly smaller widths progressing upstream to near zero at the headwaters. To account for the range in width on modeled headwater reaches, a value of one-half the width at the mouth was used in the SSSHADE model to approximate the width of the entire reach.

Topography: The topographic contribution to stream shade was assumed to be zero for most reaches. Only the two uppermost stream reaches of the mainstem Chehalis River in the Willapa Hills were assumed to have 40percent topographic shade. Using the most extreme value of zero, topographic shade for the remaining streams serve as another element of the inherent margin of safety.

Vegetation Height: This was estimated from the Washington Department of Natural Resources GIS tree canopy coverage along each stream reach. Even though there are a number of tree species in the basin (e.g. Douglas Fir and Bigleaf Maple), the conifer species modeled were assumed to be Western Hemlock, since climax stands in this region would be dominated by this species (Cassidy, 1997). Early seral stage was assumed to be 50 years and mid-seral stage at 100 years. Hardwoods were assumed to be early seral stage Red Alder at 10 years, since this is the primary species for successional starts after disturbance in mesic areas such as stream riparian corridors (Cassidy, 1997). Tree heights were derived from regional growth curves assuming a site index of 100 (Henderson, et al. 1989). Non-forested areas were assumed to be an even mix of early seral stage hardwoods, with treeless streambanks mostly supporting understory species, shrub fields, or meadows.

Vegetation Crown: This measurement was derived for a particular tree species from the ratio of the measured crown to the measured height of mature trees (B.C. Conservation Data Centre, 1999)

Vegetation Offset: Assuming typical streams will have a channel migration zone greater than the wetted perimeter, a I 0-foot offset was used for all riparian vegetation when modeling shade levels.

Vegetation Density: An 85% density was assumed to represent a fir stand with good quality of shade from existing riparian vegetation.

Model Calibration and Validation

The model was calibrated to allow it to represent more closely the particular sensitivities of the stream network. Manning's n and lateral inflow temperature were adjusted within reasonable levels so that predicted temperature more closely matched measured temperature. The period representing August 1991 was used for calibration. The model performance was validated using an independent data set of variables with the same values. Data from a different period are commonly used to assess calibration. . The period representing August 1992 was used for validation. The framework schematic, main parameters, and variables used in the model geometry are shown below (Figure 2 and Table 4).

Table 4. Upper Chehalis River Network Stream Temperature Model Geometry,Paxameters

Stream Reach Name	Elevation (m)	Azimuth (degrees bearing	Manning n	Width (m)	Width Coefficient	Width Exponent
Chehalis RM `123:0	483	5	0.040	26.8	27:01	0.14
Chehalis RM 100.2	85	80	0.040	22.6	22.06	0.14
Chehalis RM 88.3	59	80	0.040	22.6	22.06	0.14
Chehalis RM 75.4	49	0	0.060	23.6	19:75	0.18
Chehalis RM 74.7	48	0	0.060	23.6	19.75	0.18
Chehalis RM 69.4	47	0	0.060	23.6	19.75	0.18
Chehalis RM 67.0	46	-50	0.060	39.6	23.78	0.20
Chehalis RM 61.9	36	-50	0.060	39.6	23.78	0.20
Chehalis RM 88.8	34	-50	0.060	39.6	23.78	0.20
Chehalis RM 75.6	18	-50	0.060	39.6	23.78	0.20
South Fork Chehalis	281	0	0.040	6.3	10.67	0.21
Newaukum River	908	-70	0.060	4.4	10.67	0.21
Dillenbau Creek	162	-70	0.060	1.4	10.67	0.21
Salzer Creek	166	-90	0.080	1.7	10.67	0.21
Skookumchuck River	65	70	0.020	6.5	10.67	0.21
Lincoln Creek	180	90	0.080	3.1	10.67	0.21
Scatter Creek	101	85	0.025	3.5	10.67	0.21
Black River	27	55	0.060	13.1	10.67	0.21

Four statistical tests were applied to the results of the model calibration and validation. The root mean square error, median absolute deviation, scaled residuals, and relative error are the best statistical measures commonly used to test model performance (Reckhow, et al. 1986). The root mean square error presents an estimate of the variation in the same units as the measurement (e.g. °C). The relative error presents this variation as a percentage of the measurement mean. The median absolute deviation describes the central tendency of model performance. The median scaled residual provides a relative estimate, whether the model is over- or under-predicting measured conditions. These statistics were compiled for the combined data set of 10 mainstem Chehalis River stations and eight tributary stations near the mouths of the streams (Table 5).

Table 5. Performance of the Upper Chehalis River Network Stream Temperature Model in Predicting Maximum Daily Temperature

Location	Calibration - August 1991			Validation - August 1992		
	Measured (°C)	Predicted (°C)	Delta (°C)	Measured (°C)	Predicted (°C)	Delta (°C).
Chehalis River Mile 106.3	15.3	16.0	0.7	18.1	15.6	-2.5
Chehalis River Mile 88.3	18.1	20.1	2.0	18.1	19.7	1.6
-Chehalis River Mile 75.4	23.4	22.7	-0.7	23.4	22.2	-1.2
Chehalis River Mile 74.7	23.0	22.1	-0.9	21.7	21.8	0.1
Chehalis River Mile 69.4	19.2	22.1	2:9	20.1	21.3	1.2
Chehalis River Mile 67.0	21.7	21:7	0.0	22.6	20.9	-1.7
Chehalis River Mile 61.9	22.6	22.8	0.2	22.9	22.5	-0.4
Chehalis River Mile 55.2	21.3	20.9	-0.4	20.8	21.6	0.8
-Chehalis River Mile 47.0	22.1	21.9	-0.2	19.5	21.9	2.4
Chehalis River Mile 33.8	19.8	21.7	1.9	21.2	21.6	0.4
South Fork Chehalis Mouth	21.2	21.1	-0.1	20.4	20.1	0.1
Newaukum River Mouth	17.7	20.9	3.2	20.5 .	20.5	0.0
Dillenbau Creek Mouth	18.8	21.0	2.2	18.6	20.4	1.8
Salzer Creek Mouth	19.2	19.3	0.1	18.2	20.1	1.9
Skookumchuck River Mouth	20.4	18.7	-1.7	18.7	18.9	0.2
Lincoln Creek Mouth	19.0	21.8	2.8	16.2	21.4	5.2
Scatter Creek Mouth	20.9	20.7	-0.2	21.1	20.2	-0.9
Black River Mouth	21.0	20.1	-0.9	18.7	20.5	1.8
Statistics						
Median Absolute Deviation	0.8°C			1.2°C		
Median Scaled Residual	0.5%			1.6%		
Root Mean Square Error	2.6°C			2.6°C		
Relative Error	13%			13%		

The results of these statistical tests show little difference between model performance of the model calibration and validation runs. The median absolute deviations for both time periods are similar at 1.4°C and 1.5°C. The median scaled residuals show a low percentage, with the calibration run slightly under-predicting and the validation run slightly over-predicting measured stream temperatures overall. Also, the model root mean square error for predicting daily maximum stream temperature for both time periods is 3.2°C, which provides a relative error of 16%. These error measures are reasonable, based on the difficulty of predicting maximum daily temperatures (Bartholow, 1989).

Reviewing model performance at specific sites provides some insight on important factors. Near the headwaters of the mainstem, the maximum temperature is over-predicted. This is likely due to the model not representing the effects of water moving from the surface into the ground water in this reach as fit moves from bedrock into alluvium. The model also under-predicted maximum temperature in the pooled reach of the mainstem Chehalis River between the confluence of the Newaukum and Skookumchuck Rivers.. This is likely due to modeling only surface temperatures in a thermally stratified water. Overall, the model performance is adequate to test the effect of different management strategies on the temperature of the stream network as a whole.

Model Application

Using the water quality model to determine the loading capacity and evaluate alternative management strategies requires defining the critical conditions when pollutant loading has the greatest impact on attaining water quality standards. For this analysis, three factors were used to define critical conditions: flow, climatic, and solar apex. For flow, critical conditions are defined in the state's water quality standards as the statistical 7-day low flow event that occurs every 10 years (710). For climate variables, the 90" percentile maximum air temperature measured at Olympia Airport in the summer (June-August) over the past 50 years was used (31.1 °C). The other concurrent climatic variables (wind speed and relative humidity) were used from the latest date that this maximum temperature was measured (July 21, 1998). For solar apex, the day with the maximum day light was used (June 21). All of these critical conditions occur during the same period that standards are not being met in the watershed (Table 2)

Two factors that influence stream temperatures were assessed with the SNTEMP model: instream flow and wetted width-to-depth ratios of tributary stream channels. Changes on instream flow can affect the heat-carrying capacity of the stream and influence the degree at which ground water affects temperature. Changes in width-to-depth ratio affect the amount of solar load that reaches the streambed. Excessive sediment loading can cause stream channels that are shallow and wide, increasing both solar radiation loading and stream temperature.

The Upper Chehalis River system has had base flows established) at 14 locations, by state rule (Chapter 173-522 WAC) for the protection of instream uses (e.g. salmonid habitat). Recent assessments show that streams are not meeting these flows between 33 to 77 days per year. (Wildrick, et al. 1995). The water rights and claims exceed the critical low flow conditions (7Q 10) by 400%.

The calibrated network model was used to determine the effect on stream temperatures if the instream flows set by rule were met. Critical conditions were used except for the added base flow established by rule. The instream flow rule for baseflow on July 1 was used to correspond to the critical period with the highest stream temperatures (Table 2). Streams with no base flow rule were left at 7Q10 flows for the model simulation.

Results show that only one listed segment would meet the temperature criterion of 18°C, if the base flows from the rule were attained (Table 6). In addition, most other listed segments are much closer?? to compliance with the standard. This result raises the question of whether the temperature criterion represents the water quality standard. If natural conditions result in . temperature values higher than the criterion, then the naturally higher temperature values become the standard.

Table .6. Comparison of Temperature Criterion with Predicted Maximum Daily Temperature Under Instream Flow Rule Compliance.

Section 303(d)Listed Segment Name	Listed River Mile	Segment Township-Range-Section	Predicted Maximum Daily Temperature °C	Amount Above Criterion (°C
Chehalis River	101.7	13N-05W-12	16.9	0
Chehalis River	74.6	14N-03 W-24	21.1	3.1
Chehalis River	73.6	14N-03 W-25	21.2	3.2
Chehalis River	70.7	14N-02W-24	21.6	3.6
Chehalis River	69.1	14N-02W-18	22.0	4.0
Chehalis River	67.5	14N-02W-07	22.3	4.3
Chehalis River	66.3	14N-03W-12	22.4	4.4
Chehalis River	59.9	15N-03W-22	22.2	4.2
Chehalis River	44.0	16N-05W-36	21.2	3.2
Chehalis River	33.8	17N-05W-28	19.5	1.5
South Fork Chehalis	0.5	13N-04W-24	19.3	1.3
Newaukum River	0.1	14N-02W-31	20.9	2.9
Dillenbau Creek	0.1	14N-02W-31	20.9	2.9
Dillenbau Creek	1.7	13N-02W-05	21.0	3.0
Salzer Creek	0.2	14N-02W-19	21.7	3,7
Skookumchuck River	0.1	14N-02W-07	19.6	1.6
Lincoln Creek	4.2	15N-03 W-29	23.0	5.0
Scatter Creek	1.3	15N-03W-08	21.8	3.8
Black River	1.2	15N-04W-05	19.6	1.6

The calibrated network model was also used to determine the effect of channel morphology on stream temperatures. A width-to-depth ratio of 10 or less is, commonly used as describing good anadromous fish habitat (USDA, 1995). The Chézy-Manning formula (Lindsley, et al. 1982) was used with modeled parameters to determine the change in the headwater streams' wetted width and model width coefficient term that would be required to meet the target width-to-depth ratio of 10. The channel morphology of the other modeled reaches of the mainstem Chehalis River was not altered, since it is unlikely that management of sediment loads would affect the channel due to the existing hydromodification, such as extensive levies. Critical conditions were used for all other model parameters.

Results show that only one of the listed segments would meet the temperature criterion of 18°C if the width-to-depth ratio were 10 in the modeled headwaters (Table 7). Again, this result raises the question of whether the temperature criterion represents the water quality standard. If natural conditions result in temperature values higher than the criterion, then the naturally higher temperature values become the standard.

Table 7. Comparison of Temperature Criterion with Predicted Maximum Daily Temperature With Width-to-Depth Ratios of 10 in Headwater Streams

Section 303(d) Listed Segment Name	Listed River Mile	Segment Township-Range-Section	Predicted Maximum Daily Temperature °C	Amount Above Criterion (°C
Chehalis River	101.7	13N-05W-12	17.2	0
Chehalis River	74.6	14N-03 W-24	22.9	4.9
Chehalis River	73.6	14N-03 W-25	23.1	5.1
Chehalis River	70.7	14N-02W-24	23.4	5.4
Chehalis River	69.1	14N-02W-18	23.9	5.9
Chehalis River	67.5	14N-02W-07	24.1	6.1
Chehalis River	66.3	14N-03W-12	23.8	5.8
Chehalis River	59.9	15N-03W-22	23.5	5.5
Chehalis River	44.0	16N-05W-36	23.6	5.6
Chehalis River	33.8	17N-05W-28	23.4	5.4
South Fork Chehalis	0.5	13N-04W-24	22.6	4.6
Newaukum River	0.1	14N-02W-31	23.1	5.1
Dillenbau Creek	0.1	14N-02W-31	20.9	2.9
Dillenbau Creek	1.7	13N-02W-05	21.0	3.0
Salzer Creek	0.2	14N-02W-19	21.7	3.7
Skookumchuck River	0.1	14N-02W-07	19.8	1.8
Lincoln Creek	4.2	15N-03 W-29	23.0	5.0
Scatter Creek	1.3	15N-03W-08	21.8	3.8
Black River	1.2	15N-04W-05	22.4	4.4

The SNTEMP model is constructed by linking. output results from the reach submodel SSTEMP. This model was undergone a rigorous sensitivity analysis to evaluate the parameters having the greatest effect on model results (Sullivan et al. 1990). Various input parameters were varied up to 100% of the standard value to assess the change of predicting maximum daily temperatures. Results of the analysis for medium-sized streams show that the climatic factors of air temperature and humidity had the greatest influence on relative model sensitivity (Table 8).

Table 8. Ranked Sensitivity of Model Parameters in Predicting Maximum Daily Temperature (from Sullivan et al 1990):

Parameter	Change in Prediction of Maximum Daily Temperature
Air Temperature	15.2
Humidity	7.6 .
Solar Radiation	5.2
Shade	-1.6
Wind Seed	-0.7-
Stream Depth	0.7
Travel Time	-0,6
Groundwater	-0.3
Inflow Water Temperature	0.02

Loading Capacity Analysis

Identification of the loading capacity is an important step in developing TMDLs. .The loading capacity provides a reference for calculating the amount of pollutant reduction needed to bring a water into compliance with water quality standards. By definition, a TMDL is the sum of the allocations. Ari allocation is defined as the portion of a receiving water's loading capacity that is assigned to a particular source. EPA defines the loading capacity as "the greatest amount of loading that a water can receive without violating water quality standards."

In order to determine the loading capacity, the water quality criteria for each listed segment must be determined. The high temperatures involved and the application of the model to influencing factors in the previous section, suggest that the water quality standard may actually be above the general criterion of 18°C due to natural conditions. The calibrated stream network model was used to estimate naturally-occurring maximum daily temperatures under critical climate conditions.

Three factors were used to assess natural conditions. First, it was assumed that all the stream riparian corridors would have a late seral stage Western Hemlock forest stand of 200 years old (Cassidy, 1997). Second, it was assumed that the critical low flows would be affected by the amount of current human withdrawal. Linear regression of the annual streamflow values for the Chehalis River indicate a decrease of about 10% since 1930 (Wildrick et.al. 1995). To estimate natural conditions for the model, critical low flow values of streams were increased by 1~0 percent, and point source flows were eliminated. Third, the width-to-depth ratios of the headwater streams were adjusted in the model to conform to expected values for the particular channel type. Streams were classified according to stream types defined by Rosgen (1996) and the mean width-to-depth ratio reported was used in the model.

The segment-specific water quality criteria were then determined from these estimates. The model [redicts that 11 of the listed segments naturally exceed the 18°C general criterion. For these, the site-specific criterion is the natural condition temperature plus 0.3°C. The other eight listed segments were below the 18°C numeric criterion. For these segments; the numeric criterion of 18°C applies (Table 9)

Table 9. Predicted Natural Maximum Daily Temperature under Critical Conditions

Section 303(d) Listed Segment Name	Listed River Mile	Segment Township-Range-Section	Predicted Maximum Daily Temperature °C	Amount Above Criterion (°C
Chehalis River	101.7	13N-05W-12	12.9	18.0
Chehalis River	74.6	14N-03 W-24	17.8	18.0
Chehalis River	73.6	14N-03 W-25	18.1	18.4
Chehalis River	70.7	14N-02W-24	18.6	18.9
Chehalis River	69.1	14N-02W-18	19.2	19.5
Chehalis River	67.5	14N-02W-07	20.0	20.3
Chehalis River	66.3	14N-03W-12	20.1	20.4
Chehalis River	59.9	15N-03W-22	20.4	20.7
Chehalis River	44.0	16N-05W-36	20.6	20.9
Chehalis River	33.8	17N-05W-28	20.7	21.0
South Fork Chehalis	0.5	13N-04W-24	17.3	18.0
Newaukum River	0.1	14N-02W-31	17.5	18.0
Dillenbau Creek	0.1	14N-02W-31	17.2	18.0
Dillenbau Creek	1.7	13N-02W-05	17.2	18.0
Salzer Creek	0.2	14N-02W-19	19.6	19.9
Skookumchuck River	0.1	14N-02W-07	17.5	18.0
Lincoln Creek	4.2	15N-03 W-29	20.0	20.3
Scatter Creek	1.3	15N-03W-08	19.8	20.1
Black River	1.2	15N-04W-05	17.5	18.0

For comparison to present conditions, the stream network model was used to estimate the maximum temperature under critical flow and climate conditions using the current estimated riparian shade levels and channel morpholgy. These estimates of the current condition were then compared to the site-specific water quality criteria determined above. Only the listed segment in the Chehalis River headwater reach showed standards currently being met. All other listed segments are out of compliance with water quality standards (Table 10).

Table 10. Comparison of Water Quality Standards with Predicted Maximum Daily Temperature with Existing Shade under Critical Conditions

Section 303(d) Listed Segment Name	Listed River Mile	Segment Township-Range-Section	Predicted Maximum Daily Temperature (°C)	Amount Above Criterion (°C)
Chehalis River	101.7	13N-05W-12		
Chehalis River	74.6	14N-03 W-24		
Chehalis River	73.6	14N-03 W-25		
Chehalis River	70.7	14N-02W-24		
Chehalis River	69.1	14N-02W-18		
Chehalis River	67.5	14N-02W-07		
Chehalis River	66.3	14N-03W-12		
Chehalis River	59.9	15N-03W-22		
Chehalis River	44.0	16N-05W-36		
Chehalis River	33.8	17N-05W-28		
South Fork Chehalis	0.5	13N-04W-24		
Newaukum River	0.1	14N-02W-31		
Dillenbau Creek	0.1	14N-02W-31		
Dillenbau Creek	1.7	13N-02W-05		
Salzer Creek	0.2	14N-02W-19		
Skookumchuck River	0.1	14N-02W-07		
Lincoln Creek	4.2	15N-03 W-29		
Scatter Creek	1.3	15N-03W-08		
Black River	1.2	15N-04W-05		

The Upper Chehalis River Basin TMDL utilizes a measure other than "daily loads " to fulfill requirements of Section 303(d). Although heat loads can be derived and allocated (e.g. joules per square meters per day), they are of limited value in guiding management activities needed to solve identified water quality problems. Instead, the Upper Chehalis River Basin TMDL is expressed in terms of vegetative shade as a surrogate to thermal load, as allowed under EPA regulations [defined as "other appropriate measures" in 40 CFR § 130.2(i)]. A decrease in shade, as the result of a lack of adequate riparian vegetation, .causes a subsequent increase in solar radiation and thermal load.

Since the loading capacity will be presented in units of shade, the next step is to determine the amount of shade required to meet the site-specific criterion. The loading capacity determined is dependant on the parameters assumed in the model. Stream morphology is the most significant factor that is manageable to some degree. Therefore, the. loading capacity depends on the type of stream morphology modeled.

The loading capacity for each of the modeled reaches was determined by adjusting the vegetative e values in the model such that the temperature standard was dust met at each listed segment. Tic SNTEMP model does not provide results on the actual solar radiation load which would be of limited use for management anyway. The resulting loading capacities for streams ' m the Chehalis River Basin TMDL are presented in units of percent vegetative shade (Table 11).

Two separate loading capacities are derived for each of the modeled reaches: (1) required shade with the existing tributary channel form, and (2) required shade with stable tributary channel forms. Stable channel forms are defined as the mean width-to-depth ratio measured by Rosgen (1996) for each specific channel type. These loading capacities are compared to the estimated amount of vegetative shade that is achievable by allowing the existing riparian corridor to mature to a late seral stage (Table 11). The mature riparian shade is estimated using SSSHAD by modeling existing species at late seral stage without species replacement. Late seral stage for existing conifers was derived at an average site index of 100, in a Western Hemlock-dominated forest. of 200 years, with a height of 125 feet. Late seral stage for existing hardwoods was derived at an average site index of 100, in a Red Alder-dominated forest of 60 Years, with a height of 100 feet (Table A3).

Table 11. Loading Capacities for Upper Chehalis River Basin Stream Reaches

Stream Reach	Percent Vegetative Shade		
	Existing Channel Morphology	Stable Channel Morphology	Achievable Late Seral Stage Shade
Chehalis River – Headwaters to Elk Creek	49%	20%	75%
Chehalis River – Elk Creek to Newaukum River	48%	48%	53%
Chehalis River – Newaukum River to Skookumchuck R.	64%	64%	64%
Chehalis River – Skookumchuck R. to Scatter Creek	43%	43%	47%
Chehalis River – Scatter Creek to the Town of Porter	44%	44%	47%
South Fork Chehalis	85%	74%	82%
Newaukum River	84%	78%	78%
Dillenbau Creek	85%	77%	85%
Salzer Creek	81%	80%	85%
Skookumchuck River	79%	70%	81%
Lincoln Creek	78%	78%	84%
Scatter Creek	81%	80%	85%
Black River	79%	68%	75%

Comparison of the two loading capacities demonstrates that achieving maximum shade from a late seral stage riparian corridor will not alone be sufficient to meet the temperature standard for three of the tributaries. The South Fork Chehalis River, the Newaukum River, and the Black River will also need to reduce the width-to-depth ratio to meet temperature standards. Therefore, the loading capacity for these streams assumes that stable channels are formed by managing the processes affecting them.

Load Allocations

The load allocations established are the same as the loading capacity with existing channel morphology except for three reaches. For the South Fork Chehalis River, the Newaukum River, and the Black River, the load allocation is based on achieving a stable channel with decreased width-to-depth ratios. The load allocations were compared to the estimated existing shade derived for the model calibration and validation (Table A1). Only the Chehalis River headwater reach currently meets the load allocation. The other streams all need additional shade, ranging from 12% to 42% (Table 12).

Table 12. Loading Capacities for Upper Chehalis River Basin Stream Reaches

Stream Reach	Percent Vegetative Shade		
	Load Allocation	Estimated Existing Shade	Additional Shade Needed
Chehalis River – Headwaters to Elk Creek	49%	53%	0%
Chehalis River – Elk Creek to Newaukum River	48%	18%	30%
Chehalis River – Newaukum River to Skookumchuck R.	64%	22%	42%
Chehalis River – Skookumchuck R. to Scatter Creek	43%	16%	27%
Chehalis River – Scatter Creek to the Town of Porter	44%	16%	28%
South Fork Chehalis	74%	52%	22%
Newaukum River	78%	43%	35%
Dillenbau Creek	85%	64%	21%
Salzer Creek	81%	68%	13%
Skookumchuck River	79%	59%	20%
Lincoln Creek	78%	59%	19%
Scatter Creek	81%	70%	12%
Black River	68%	37%	31%

Per EPA, guidance; a ;quantitative link to a manageable pollutant should be shown; in order to use a surrogate measure such as channel .morphology, as, a factor in n load-Allocation. In this case, the widening of the streams may have occurred, because of a: .greater than normal, input ;of sediment to the stream system through erosion processes. Two approaches were investigated to quantify stream width-to-depth ratios to rneasures: of erosion.

First, a relationship vas investigated between width-to-depth-data collected as part of the . v Regional Environmental, Monitoring and Assessment -Program (Merritt; 199:7 and the. percent ;of bank erosion observed by the U.S Fish and Wildlife Service (Wampler et al. 1993) in the watershed upstream of these sample locations. There was essentially no predictive relationship between these data sets; with a nonsignificant explained variance of only.6 percent. Data transformation did not improve this regression.

Second, a relationship was investigated: between the width-to-depth data collected _a& part of the, Dry Season TMDL, study (Pickett; 1994a) and historical sediment loading-a collected by the U.S. Geological Survey (Glancy, 1966). Data collected since this time are not adequate to derive more reasonable, current loading estimates: Again, there was essentially no predictive . relationship between these data sets with a non-significant explained variance of only 25 percent. Data transformation did not improve this regression.

These analyses show that with existing information, the stream morphology cannot be quantitatively linked to a manageable pollutant, as requested by EPA guidance for TMDLs. Therefore; specific numeric load allocations for sediment load cannot be established. .However, the assumed channel width-to-depth ratio required to meet the load allocation described by shade can be used as a target. Only the three tributaries (South Fork Chehalis River, the Newaukum River, Black River) need to reduce mean width-to-depth ratios to -achieve the load allocations. All other reaches must at least maintain existing channel morphology to meet the load allocation. (Table 13).

Table 13. Mean Tributary Width-to-depth Ratios (W.D) Needed to Meet Load Allocations

Stream Reach	Existing Mean W:D	Required Mean W:D	Percent Reduction
South Fork Chehalis	82	17	80%
Newaukum River	60	17	72%
Dillenbau Creek	83	83	0
Salzer Creek	135	135	0
Skookumchuck R.	67	67	0
Lincoln Creek	135	135	0
Scatter Creek	147	147	0
Black River	7.1	27	62%

The load allocations are based on two assumptions: 1) riparian vegetation will be protected and re-established as the result of management actions, and 2) water quality will be degraded no further by other influences. Although the bulk of this analysis focused on riparian shade, the calibration of the model resulted in estimates of ground water inflow, stream and tributary flow, and channel morphology of the stream. Since the model was calibrated to predict current conditions, the implication of these assumptions is that existing influences on temperature other than shade must remain constant in order for the shade allocations to effectively control in-channel water temperatures. Since alterations of them would affect the assimilative capacity of the stream, existing groundwater inflow, stream flow, tributary flow, and channel morphology are considered part of the load allocation. Further degradation of these factors could affect the loading capacity of heat and may result in temperature standards not being met.

Instream flow levels at critical low flows must remain the same. Any additional water withdrawals must not be allowed during critical low flow periods. This includes any groundwater withdrawals with continuity to streams. Control measures need to be implemented to prevent further flow depletion. Restoration of flow levels more like pre-European settlement would probably further improve the rivers' temperatures.

Processes that affect channel morphology must at least be held constant for most streams. For the South Fork Chehalis River, the Newaukurn River, and the Black River, the process affecting channel morphology must be improved to achieve stable channels with decreased width-to-depth ratios. The more significant factors affecting stream morphology that must be at least held constant are sediment delivery and watershed hydrology. Restoration activities that would reconnect or reestablish side channels, back-waters, and riverine wetlands would probably further improve channel water temperatures.

Sediment delivery to the streams must be held constant or reduced. Excessive sediment loading to streams can raise temperatures. Surface erosion and sediment delivery from mass wasting must not increase.

Watershed hydrology must not be further altered. Activities that shift hydrographs from baseflow to more surface storm flow will affect temperatures. Excessive storm flows can result in further stream bank erosion and will likely raise stream temperatures. Lower base flow in the summer caused by the hydrograph shift will also likely raise stream temperatures. Expansion of dikes and levies that could further alter stream hydrology should be curtailed.

The load allocations described also apply to all tributary streams to the modeled reaches. The load allocations are based on the assumption that lateral temperatures and flows are held at current level. Lateral inflow represents all the smaller surface tributaries and ground water inflow to the segments which are not specifically modeled. These temperature and flows must not get worse. Activities that increase the temperature, reduce the flow, or impact the stream channel forming processes must be prevented in all tributaries of the watershed.

Finally, these load allocations do not apply to streams in state and private forest lands. During the 56th Legislature, ESHB 2091 was passed during special session. This legislation codified a multi-stakeholder agreement (known as the "Forests and Fish Report") as it affects the recovery of salmon and water quality. It provides a set of federal and state assurances for Clean Water Act Section 303 (in Schedule M-2). In the report, EPA and Ecology have concurred that TMDLs, for temperature and other water quality problems, need not be prepared prior to July 2009 on state and private forest lands subject to the agreement. For these forested lands in the Upper Chehalis River Basin, the Forests and Fish Report provides the regulatory mechanism for pollution control, and not the allocations defined by this TMDL.

The Forests and Fish Report improves the management-of the riparian corridor over what is currently done. The riparian strategies described in the agreement are designed to result in a mature riparian corridor. These strategies meet the same goals as set forth in this TMDL. Since the goals of the agreement are the same goals as the TMDL, the effect of the agreement is only administrative. The result of implementing the provisions of the Forests and Fish Report are expected to bring the waters into compliance with water quality standards for temperature, eliminating the need for a TMDL.

Wasteload Allocations

Three of the four point source discharges enter the river close together. This is the reach of the mainstem Chehalis River that exceeds the standard of 18°C under critical natural conditions. As such, the temperature standard for that reach is 0.3°C above the natural condition. The entire heat load that allows this 0.3°C rise in temperature has been allotted to nonpoint sources as load allocations. The discharge temperatures allotted to the three point sources have been set to the level that would cause no increase in river temperature. This sets the wasteload allocation to an insignificant effect level.

This allocation strategy is required by EPA (1991) when there are no reasonable assurances provided that nonpoint source reductions will be achieved. Without these assurances, wasteload allocations must be established based on the assumption that the nonpoint sources will not be reduced. Therefore, the wasteload allocation set for the three point sources are the highest discharge temperature that would cause no increase in the river temperature.

A sensitivity analysis approach was used to determine the no-effect level of discharge temperatures for, each of the four point sources. The calibrated model was used at critical conditions to determine the maximum discharge temperature of each point source. The discharge temperatures were incrementally raised in steps of 0.1 °C until the predicted maximum daily river temperature at the next downstream listed segment was just increased. The Darigold and Chehalis WWTP discharges, which are very close together, were raised in the model at the same temperature. The greatest discharge temperature that showed no increase in river temperature was set as the wasteload allocation.

The model predicts the effect on the temperature of the nearest reach downstream of the discharge (Table 14). Since no mixing zone analysis was conducted, the resulting effluent temperatures apply at the point of discharge. Also, since the analysis setting the wasteload allocations was conducted using critical conditions, the effect of the discharge will not impact the river during other periods. As a margin of safety for these other periods, these wasteload allocations apply year round. The discharge temperatures shown in Table 14 serve as the wasteload allocations for the point sources.

Table 14. Wasteload Allocations as Effluent Discharge Temperatures

Facility	Discharge Location (River Mile)	Downstream Listed Segment Location (River Mile)	No Effect Discharge Temperature (°C)
Pe Ell Wastewater Treatment Plant	105.5	101.7	26.0
Darigold Wastewater Treatment Plant	74.4	73.6	29.8
Centralia Wastewater Treatment Plant	74.3	73.6	29.8
Centralia Wastewater Treatment Plant	67.4	66.3	34.6

Margin of Safety

The statute requires that a margin of safety be identified to account for uncertainty when establishing a TMDL. The margin of safety can be explicit in the form of an allocation, or implicit in the use of conservative assumptions in the analysis. Several assumptions and critical conditions used in the modeling analysis of the Chehalis River TMDL provide an inherent margin of safety over uncertainty as required by the statute. These conservative. assumptions and critical conditions are listed below:

1. The highest water temperatures recorded in August were used to calibrate and validate the model. Lower water temperatures were recorded at various times and locations. As such, the model represents the worst case condition measured in the system.
2. The topographic shade was set to zero for all of the streams modeled, except for the headwater reaches of the mainstem Chehalis River. Several of the stream reaches benefit from shade caused by the steeper topography of the surrounding hills block additional solar radiation. This benefit was disregarded in the modeling.
3. The lowest latitude of the study area was used for all modeled reaches. Some of the reaches are at a slightly higher latitude and could have a smaller solar radiation load at certain times.
4. Used 100% sunshine in all model runs. Clouds that could block solar radiation were not accounted for in the model.
5. Ten-year, 7-day low flows derived by Pickett, (1994a) were used for loading capacity analysis and management strategies.
6. Climate conditions recorded on the 90L' percentile maximum daily measured temperature were used.
7. The date of June 21 was used for the maximum annual solar radiation.

The modeling results and the loading capacity show that existing shade levels and some channel forms are not sufficient to meet stream temperature standards in the Upper Chehalis River Basin. The implementation strategy of passive restoration of the riparian corridor will meet the load allocations established. First, the existing riparian vegetation must be maintained on all riparian areas. Passive restoration entails allowing the existing riparian vegetation to grow into a mature forest (e.g. late seral stage). This implementation strategy will meet the load allocations by increasing shade to adequate levels. Second, passive riparian restoration will also reduce the sediment loads so that channel morphology can stabilize in the South Fork Chehalis River, the Newaukum River,, and the Black River. Recent research has shown that streamside buffers are effective at preventing sediment delivery and direct physical disturbances to streams (Rashin et al. 1999). A mature riparian corridor will also improve temperatures by supplying adequate large wood for proper channel forming processes. A passive restoration approach would result in all listed segments meeting temperature standards by the time existing vegetation reaches late seral stage (Table 15).

Table 15. Comparison of Temperature Standards with predicted Maximum Daily Temperatures under Critical Conditions using a Passive Restoration Strategy

Section 303(d) Listed Segment Name	Listed River Mile	Segment Township-Range-Section	Predicted Maximum Daily Temperature (°C)	Water Quality Standard (°C)	Amount out of Compliance (°C)
Chehalis River	101.7	13N-05W-12	16.1	18.0	0
Chehalis River	74.6	14N-03 W-24	17.5	18.0	0
Chehalis River	73.6	14N-03 W-25	18.0	18.4	0
Chehalis River	70.7	14N-02W-24	18.6	18.9	0
Chehalis River	69.1	14N-02W-18	19.1	19.5	0
Chehalis River	67.5	14N-02W-07	19.5	20.3	0
Chehalis River	66.3	14N-03W-12	19.4	20.4	0
Chehalis River	59.9	15N-03 W-22	20.0	20.7	0
Chehalis River	44.0	16N-OSW-36	20.5	20.9	0
Chehalis River	33.8	17N-05W-28	20.6	21.0	0
South Fork Chehalis	0.5	13N-04W-24	21.0	18.0	0
Newaukum River	0.1	14N-02 W-31	16.9	18.0	0
Dillenbau Creek	0.1	14N-02W-31	17.9	18.0	0
Dillenbau h Creek	1.7	13N-02W-05	17.8	18.0	0
Salzer Creek	0.2	14N-02 W-19	17.9	18.0	0
Skookumchuck River	0.1	14N-02W-07	19.3	19.9	0
Lincoln Creek	4.2	15N-03 W-29	17.8	18.0	0
Scatter	1.3	15N-03 W-08	19.4	20.3	0
Black River	1.2	15N-04W-05	19.4	20.1	0
			17.3	18.0	0

Each modeled reach currently contains riparian vegetation that covers several different seral stages (Table A 1). Using the assumptions made on the average age of each of the seral stages defined in the modeling approach section, one can estimate how long it would take for all vegetation in any particular reach to grow to late seral stage (Table 16). Reaches that are dominated with hardwoods or non-forested areas which will be replaced by hardwoods will grow to late seral stage soonest. Reaches with conifers will take considerably longer.

Table 16. Estimated Maximum Time for Each Reach to Attain Full Late Seral Stage with Existing Vegetation

Stream Reach	Years to Late Seral Stage
Chehalis River -Headwaters to Elk Creek	150
Chehalis River -Elk Creek to Newaukum River	100
Chehalis River - Newaukum River to Skookumchuck R.	60
Chehalis River -Skookumchuck R. to Scatter Creek	150
Chehalis River -Scatter Creek to the Town of Porter	150
South Fork Chehalis	150
Newaukum River	60
Dillenbaugh Creek	100
Saltier Creek	150
Sko6kumchuck River	150
Lincoln Creek	150
Scatter Creek	150
Black River	150

Summary Implementation Strategy

Implementation Plan Development

The Detailed Implementation Plan (DIP) for the Chehalis Temperature TMDL required under the Memorandum of Understanding between Ecology and U.S. EPA will be developed in conjunction with local watershed planning currently underway in the Chehalis Basin.

Implementation of the Chehalis Temperature TMDL is closely related to these watershed planning and salmon recovery activities. This local planning was initiated to meet the , requirements of recent state legislation (ESHB 2514 - Local Watershed Planning, and ESHB 2496 - Salmon Recovery) which recognized the importance of local planning and implementation to salmon recovery, water quality, and water supply. Although these are separate pieces of legislation with different emphases, they both address critical components of fish habitat. Coordination between the two is a state and local priority.

The Chehalis Basin Partnership has been recognized by the state as the Local Planning Unit for Watershed Planning under ESHB 2514, and as the Lead Entity for Salmon Recovery activities under ESHB2496.

ESHB 2514 - Local Watershed Planning

ESHB 2514 authorizes local planning units and establishes a process that will lead to effective water management within designated watersheds. Each planning unit is made up of local citizens who join together in an effort to assess the factors affecting in-stream flows, and if they choose, water quality and fish habitat. The assessment is used to develop management strategies that provide adequate flows of high quality water for fish, as well as finding ways to meet the needs of people who rely on out-of-stream uses of water.

The resulting watershed plans may be used to develop in-stream flow levels where they do not already exist, or to recommend changes to existing established minimum flows where appropriate. The local planning unit for the Chehalis Basin chose to include water quality as a component of its plan, so the plan must include recommendations for implementing TMDLs to achieve water quality standards. A primary purpose of the watershed management planning under ESHB 2514 is to address water and habitat issues affecting listed and soon-to-be listed salmon stocks under the federal Endangered Species Act.

ESHB 2496 - Salmon Recovery

ESHB 2496 addresses many aspects of salmon recovery. Of particular interest to this TMDL project is the section directing the Washington State Conservation Commission to form watershed based technical advisory groups (TAC) to complete an analysis of salmon habitat factors that limit the ability of habitat to.fully sustain natural spawning populations of salmon. Each TAC is comprised if individuals representing private, federal, state, tribal and local government entities.

The limiting factors analysis for the Chehalis Basin has already been initiated. The basin has been broken down into 15 sub-basins that have been prioritized for completion of limiting factor analysis. Within each sub-basin, the limiting factor analysis will attempt to identify all types of habitat impediments that negatively affect natural spawning salmon populations. These impediments include fish passage, riparian corridors, wetlands, water quality, water quantity and stream channel health.

The limiting factor analysis will provide a foundation for future conservation work. It will be used to identify specific riparian areas that will be a high priority foi the riparian shade protection and restoration required under this temperature TMDL.

Coordination of 2514 Local Watershed Planning and 2496 Salmon Recovery Activities with Development of a Detailed Implementation Plan

Under ESHB 2514, the local planning unit must submit a proposed watershed plan within four years of receiving funding for beginning the assessment: In the Chehalis, this means that the TMDL DIP would be completed in 2003 when the proposed watershed plan is due. This schedule does not meet the 12-month timeframe described in the TMDL MOA. However, there are three overriding reasons that it would not be a wise use of limited resources to prepare the DIP independent of the local watershed plan.

First, since the watershed plan developed under ESHB 2514 must include recommendations for implementing existing TMDLs, and because of the local commitment to meeting the requirements of both the Watershed Planning Act (ESHB 2514) and the Salmon Recovery Act (ESHB 2496), there would be little local interest in agreeing to separate TMDL implementation activities until the local watershed plan is complete. It also makes good sense to build TMDL implementation into the locally-developed recommendations in the watershed plan.

The second reason for delaying the DIP so that it is integrated with the local watershed plan ,e

developed under ESHB 2514 is that there are significant riparian zone protection and restoration efforts already underway. These efforts are consistent with any implementation activities that could be recommended in the DIP. A summary of some of the current riparian zone restoration and protection activities is provided in Table 17.

Finally, it is expected that the Bull Trout, Sea-Run Cutthroat Trout, and possibly coastal Coho will be listed within the Chehalis Basin on the federal Endangered Species Act within the next two or three years. The potential for a "take" under ESA will create real incentives for restoring and protecting riparian zones, which is the key to promoting tree growth that results in increased shade and lower water temperatures.

Local Watershed Planning Goals

The Chehalis Basin Partnership was forming as a local coordinating body before the watershed planning and salmon recovery legislation described above was passed. The Intergovernmental Agreement forming the Partnership states the following goal:

"The parties shall work cooperatively to establish a planning unit to be called the Chehalis River Basin Partnership and to seek participation from interested and affected parties. The Chehalis River Basin Partnership serving in an advisory and informational capacity, shall coordinate efforts focusing on:

- Improvement of water quality
- Management of water resources to provide ample supplies for farms, fish, industry and people (including restoration of healthy runs of salmon and steelhead)
- Reduction of the effects of flooding.
- Increase in recreational opportunities
- Increase in watershed awareness through education"

Local Watershed Planning Participants

The Chehalis Basin Partnership currently consists of representatives from the following groups: (Membership may change over time.)

- Each county with lands contributing significant flows to the Chehalis Watershed (4).
- Each interested city and town in the watershed (9 have signed on).
- The Confederated Tribes of the Chehalis Reservation and the Quinault Indian Nation.
- One representative of the water supply utilities.
- One representative of the Port Districts.
- One representative from each: the State Departments of Agriculture, Ecology, Fish & Wildlife, and Natural Resources. Ecology represents all other state agencies not specifically named.
- One private citizen from each of the counties (4).

Other major interests represented currently include the Chehalis Basin Fisheries Task Force, the Washington Cattlemen's Association; and Weyerhaeuser. A business representative position is currently vacant.

In addition to the formal members, the : US Fish and Wildlife Service, US EPA, and the US Army Corps of Engineers participate in the partnership. Other federal agencies are welcome.

Summary of Public Involvement

Public review and comment on the proposed temperature TMDL for the Upper Chehalis River was solicited through:

- Announcements in the state register.
- Advertisements in the legal sections of The Centralia Chronicle and The Olympian
- An article requesting comments on the proposed TMDL in "Drops of Water," a monthly newspaper insert distributed to newspaper subscribers in the basin by the Chehalis River Council.
- An announcement on the web-site for the Chehalis River Council.

At the request of several interested parties who were not individually notified of the review/comment period, Ecology extended the comment period one additional week for those who requested it.

Copies of the newspaper advertisements, state register notice and newsletter article are provided as Appendix C.

The response to public comments is provided in Appendix D.

Monitoring Effectiveness

There are EPA (1991) guidance calls for a monitoring plan for TMDLs where implementation will be phased in over time. The monitoring is conducted to provide assurance that the control measures achieve the expected load reductions. Monitoring can be conducted in three ways. First, the actual water temperature can be measured to test for downward trends. Second, the level of factors influencing temperature (e.g. shade) can be measured. Third, implementation can be monitored to assess the progress on implementation. There are a number of monitoring activities planned that touch on all three types of monitoring:

- Both Ecology and the. Chehalis Tribe conduct routine monitoring of surface water temperatures throughout the basin.
- The Conservation Reserve Enhancement Program will monitor the amount of land taken out of agriculture for riparian restoration.
- The Chehalis-Willapa Landscape Plan requires specific monitoring of the riparian condition in the forested areas owned by Weyerhaeuser Company.
- The Conservation Districts will monitor the amount of riparian corridor restored.
- The effectiveness monitoring .of best management practices and fisheries habitat restoration efforts is being conducted for several more years under a continuing grant from the Chehalis Fisheries Basin Restoration Program.

These monitoring activities individually provide valuable information. To effectively evaluate the short- and long-term effectiveness of riparian restoration, these programs will have to be coordinated and augmented. This will be addressed in the Detailed Implementation Plan.

Existing. Programs Implementing TMDL Recommendations for Restoring Riparian Shade .

There are many parties actively restoring riparian shade in the Upper Chehalis Basin today. Below is a description of the various programs underway to maintain or restore the riparian corridor.

Conservation Reserve Enhancement Program

The Washington Conservation Reserve Enhancement Program is a joint effort between the State of Washington and the U.S. Department of Agriculture to restore fisheries habitat on private agricultural lands adjacent to depressed or critical-condition salmon streams. The streams in the Upper Chehalis River basin have been approved for inclusion in this program. Landowners will contract with the federal Farm Services Agency to take land adjacent to these streams out of agricultural production and plant it with native trees. The trees must remain undisturbed for. up to 15 years. In return, the landowner will receive an annual rental check. In addition to the payment, grant funds that cover nearly 90% of the cost of converting the agricultural land back to trees will be available to participating landowners.

The program began in January 1999 and is being coordinated by the Washington State Conservation Commission. Local Conservation Districts market the program to landowners, assist with the lease agreements and help design the riparian restoration and protection practices. The program requires establishing a buffer that is a minimum of three-quarters of the site potential tree height. The site potential tree height is based on soil conditions, climatic conditions, and native plant communities, so it will be somewhat different for each locale. In addition to developing recommendations for re-vegetation, other practices such as livestock fencing and vegetation watering in dry periods may also be included in the site plan.

Chehalis River Council "Shade to Chehalis" Program

The Chehalis River Council is a nonprofit organization established in 1994 by a group of citizens concerned about the environmental conditions and water quality in the Chehalis River Basin. In 1995, Ecology awarded the Council a grant to develop a tree-planting program for the river basin. "Shade the Chehalis" (the name the Council has given this program) contacts shoreline residents and concerned citizens to encourage native tree planting projects along stream banks. The Council has published a tree-planting guide to help these people design and implement riparian vegetation restoration projects.

Chehalis-Willapa Landscape Plan

The Weyerhaeuser Company is developing the Chehalis-Willapa Landscape Plan, with the coordination of state agencies, under the new Landowner Landscape Planning process defined in the Forest Practice Rules (WAC 76.09.350). This Landscape Plan covers lands owned and operated by Weyerhaeuser in the southern, forested part of the Upper Chehalis River Basin. When adopted, the plan will substitute for standard forest practice rules and prescriptions designed through the state watershed analysis process (WAC 222.22). It will be reviewed annually to determine compliance with the plan requirements.

The Aquatic Resource Objectives define the elements of the draft Chehalis-Willapa Landscape Plan that relate to protection of the riparian corridor. The purpose of these objectives is to protect aquatic ecosystems from the potential adverse effects of forest practices. The Plan describes specific targets, prescriptions, required monitoring, and adaptive management triggers for the following objectives:

- Establish riparian management zones that provide the following stream functions...
    1. Protect stream bank integrity
    2. Provide adequate shade to meet or exceed targets for water quality standards
    3. Produce woody debris in sufficient quantities and of appropriate sizes and species to maintain or improve habitat quality
    4. Provide terrestrial habitat associated with riparian areas
    5. Provide nutrient input to the aquatic system
- Reduce the frequency of mass wasting failures resulting from roads and timber harvest.
- Minimize the delivery of sediment from roads and timber harvest areas to streams.
- Identify and remove road related fish blockages.

- Maintain watersheds in a condition to avoid flows at or above levels ca

Other Forest Practice Activities

Watershed analyses have been conducted in the Chehalis River headwaters, Stillman Creek, and the Skookumchuck River watersheds. These watershed analyses (conducted under WAC 22222) focus on site-specific characteristics, and establish reach-specific prescriptions for future forest management activities. Factors influencing temperature that are addressed through the watershed analysis process include riparian function, stream channel morphology, water quality, mass wasting, surface erosion, hydrology, and fish habitat.

In addition, there is new legislation derived from a proposal by several significant forest landowners to improve riparian management beyond the requirements of current forest practice rules. The strategies described in the proposal are designed to result in a mature riparian forest. These strategies meet the goals set forth in this TMDL. Part of the proposal is an agreement between EPA and Ecology to not establish TMDLs for waters managed under these riparian strategies. Since the goals of the proposal are the same goals as the TMDL, the effect of the agreement is only administrative. The result of either action will bring the waters into compliance with water quality standards for temperature.

Conservation Districts

Conservation districts are continually developing conservation plans on agricultural property throughout the Chehalis River Basin. For a farm plan to be approved by the Conservation District Board of Supervisors, it must identify all resource concerns, specify which alternative solutions the landowner has selected to address those concerns, project a schedule for implementation, and document the landowner's commitment to address all the identified concerns.

When streams or other waterbodies are part of the landowner's holdings, livestock exclusion or limited access to the riparian corridor is always a component of the plan. When the fence is built for the livestock exclusion, the riparian corridor is sometimes replanted with native trees and shrubs. The work of Lewis County Conservation District in the Deep Creek watershed is a fine example. Nearly 14,000 feet of riparian corridor has been fenced and replanted with trees since 1995.

One concern is the survival rates of the plantings. Past projects have documented a large range (10%-70%) of trees surviving after planting. The main problem contributing to low survival rates is the invasion of grasses and weeds that compete for soil nutrients and available water, and shade out the young seedlings. Other problems affecting the survival of planted trees include wildlife damage (mice, deer and beaver).and drying of soils during hot summer periods. These problems are being addressed by the use of foil or plastic to protect the ground around young trees and having landowners water and weed around the trees until they are established.

Confederated Tribes of the Chehalis Reservation

The Confederated Tribes of the Chehalis Reservation has an ongoing program to restore and protect riparian corridors. Under this program the Tribe provides technical and financial assistance to landowners that are interested in protecting riparian zones on their property. The Tribe has often been successful working with landowners who are otherwise reluctant to work with "governmental agencies." In some cases, these landowners have become active proponents of riparian zone protection. Over a five-year period (1994-1998) the Chehalis Tribe has assisted with the installation of 20.6 miles of riparian fencing, resulting in the protection of 123 acres of riparian area. In addition, they have helped install approximately six off-channel wetland/rearing habitats that provide another 40 to 50 acres of protected riparian areas.

Chehalis Basin Fisheries Restoration Program

The Chehalis Basin Fisheries Restoration Program was initiated by congressional legislation (Public Law 101-452) and is coordinated by the U.S. Fish and Wildlife Service. The goal of the program is to optimize natural salmon and steelhead production while allowing the highest compatible level of hatchery production. The program provides funding and guidance to improve aquatic habitats throughout the Chehalis River Basin.

Under this program, Ecology has implemented a six-year project to evaluate the effectiveness of best management practices and fisheries habitat restoration efforts. Numerous stream sits are being monitored and evaluated under this grant. A number of interim project reports have been published which document the effectiveness of BMPs (Sargent, 1996a&b; Sargent 1997; Sargent, 1998a&b).

In addition to monitoring the effectiveness of these activities, the program has provided grant funds to various cooperators for specific restoration activities (Table 17).

Table 17. Riparian Restoration Projects funded by the Chehalis Basin Fisheries Restoration Program.

Fiscal Year	Cooperator	Location	Project Description
1993	GHCD	Confluence of Cedar Creek and Chehalis River	7300 ft of livestock exclusion fencing.
1993	GHCD	Confluence of Cedar Creek and Chehalis River	2500 ft of fencing and riparian revegetation; 228 ft of bank stabilization w/ LWD
1993	LCD	Dillenbaugh Creek near town of Chehalis	11,000 feet livestock exclusion fencing; off channel refuge alcoves; bank stabilization; and revegetation. Five landowners.
1994	GHCD	Black River	10,000 ft. livestock exclusion fencing
1994	CBFTF	Steams Creek (Upper Chehalis near Adna)	3850 feet of livestock exclusion fencing; revegetation; and spawning pads.
1994	CBFTF	Mill Creek (Upper Chehalis near Adna)	500 feet of livestock exclusion fencing and revegetation.
1994	CBFTF	Allen Creek (Black River basin)	8911 feet of livestock exclusion fencing; 10 instream LWD structures; 1 spawning pad; and revegetation.
1994	CBFTF	Allen Creek (Black River basin)	7011 feet of livestock exclusion fencing and revegetation.
1994	CBFTF	Upper Dillenbaugh Creek	2400 feet of livestock exclusion fencing; off-channel refuge alcove; LWD placement; and bank stabilization.
1994	CBFTF & Chehalis Tribe	N. and S. Forks Lincoln Creek.	960 feet livestock exclusion fencing; 8 LWD structures; and revegetation.
1994	Chehalis Tribe	Garrard Creek	1000 ft. fencing; bank stabilization; LWD; revegetation
1994	Tilton River Company, & LCD	Lucas Creek (North Fork Newaukum basin)	318ft. bank stabilization using revegetation, log deflectors and rootwads. Most structures swept away the week after completion Bank not eroding as of 1997, additional willow planting 1997.

Table 17 Continued. Riparian Restoration Projects funded by the Chehalis Basin Fisheries Restoration Program.

Fiscal Year	Cooperator	Location	Project Description
1995	Chehalis Tribe	Garrard Creek	5,000 feet fencing, LWD placement, revegetation.
1995	TCD	Skookumchuck River/Scatter Creek	Riparian planting at 16 sites.
1995	LCD	Deep Creek	12,400 ft of fencing , revegetation, three pasture pumps and three crossings. Five landowners on creek involved.
1995	LCD	Bunker Creek	4000 ft fencing ; bank stabilization using LWD, vegetation and bank sloping; and 3,000 linear ft revegetation.
1996	TCD	Allen Creek/Black River	1,300 feet of livestock fencing, 10,000 square feet of plating, and a Conservation Plan.
1996	TCD	Dempsey Creek/Black River	11,500 feet of livestock fencing, native plantings, four pasture pumps, two livestock crossings and a Conservation Plan.
1996	TCD	Waddell Creek/Black River	700 feet of livestock fencing, revegetation, bank stabilization and instream habitat structures
1996	GHCD	Mainstem Black River	700 feet of livestock fencing, revegetation, bank stabilization and instream habitat structures
1996	LCD	Salzer Creek/China basin	4,600 feet of livestock, bioengineering and large woody debris placement for 70 feet of bank protection, and revegetation of the riparian corridor.
1997	LCD	Salzer Creek/China basin	The lower 2100 feet of Salzer Creek will be revegetated with native riparian trees and shrubs in the same

Table 17 Continued Riparian Restoration Projects funded by the Chehalis Basin Fisheries Restoration Program.

Fiscal Year	Cooperator	Location	Project Description
1997	LCD	Coal Creek/China basin	2000 feet of Coal Creek revegetated with native riparian trees and shrubs. Reed canary grass will be controlled by scalping, installing ground cover matting, and active maintenance until plants become established.
1997	TCD&GRE EN	Various CFRP project sites	Monitoring of riparian revegetation and help with maintaining existing revegetation projects. High school students, funded by the Private Industry Council, provided the data collection and labor. We provided funds for the crew leader's salary and training, and equipment. The project also included classroom activities and training for the students
1997	WDNR	OLC 1000 Road tributary to Scatter Creek	500 feet of livestock fencing, 0.6 acres of riparian planting and 10 large whole tree habitat structures
1998	GHCD .	Various CFRP project sites in GH County	Monitoring, maintenance and replanting at six GHCD/CFRP riparian revegetation sites
1998	TCD	O'Connor Creek/ Skookumchuck basin	2,600 feet of revegetation on O'Conner Creek, which has been fenced by other cooperators to exclude livestock.
1998	LCD	Kearney Creek/ S. Fork Newaukum basin	1320 feet of livestock exclusion fencing and a rocked crossing.
1998	CBFTF	Steams Creek (Upper Chehalis Basin)	700. feet of livestock fencing and revegetation.

<u>Cooperator Acronyms</u>

CBFTF - Chehalis Basin Fisheries Task Force.
LCD - Lewis Conservation District
TCD - Thurston Conservation District
GHCD - Grays Harbor Conservation District
GREEN - Global Rivers Environmental Education Network
WDNR - Washington State Department of Natural Resources

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FIGURES

Study Area Location Map

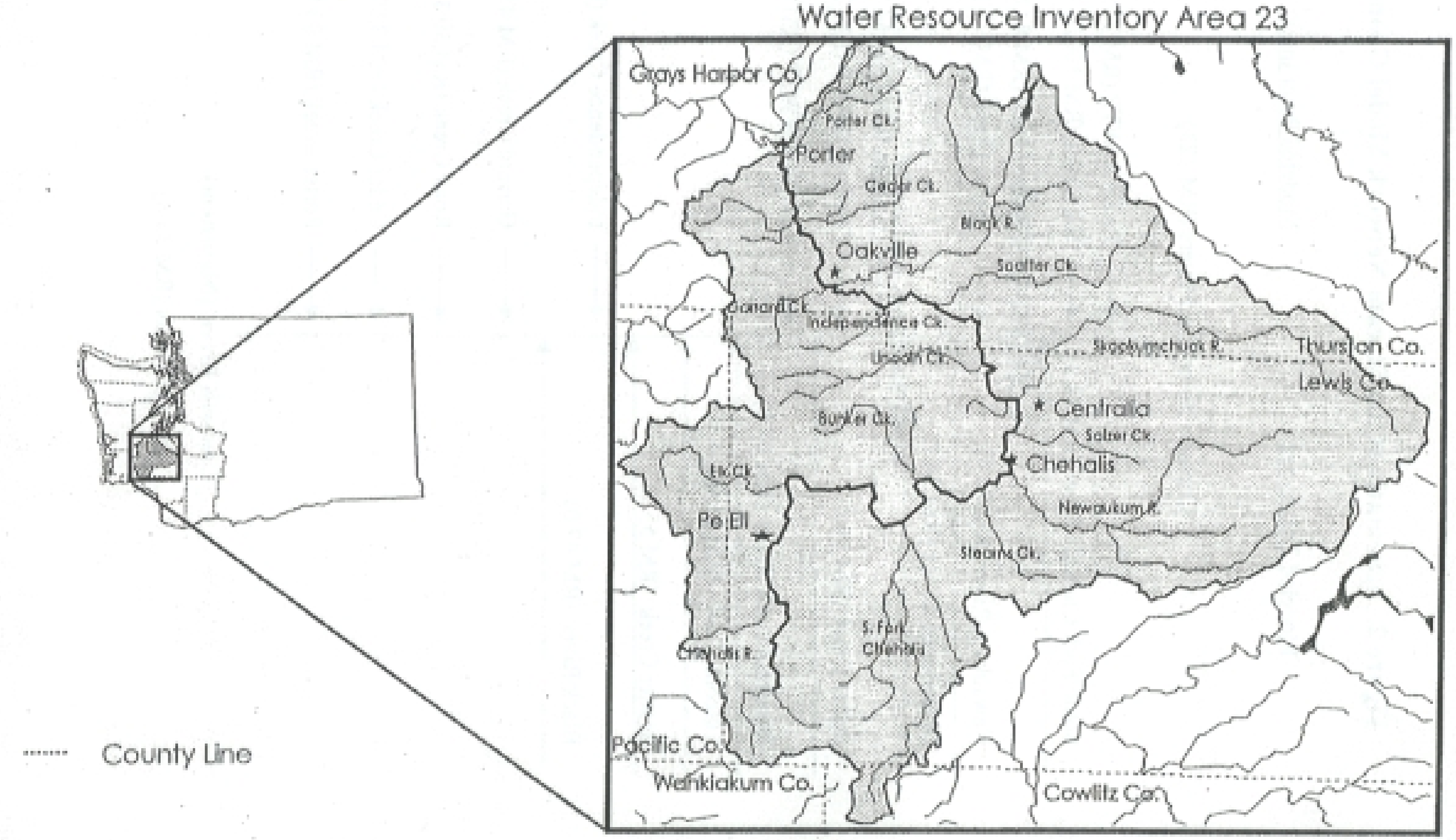
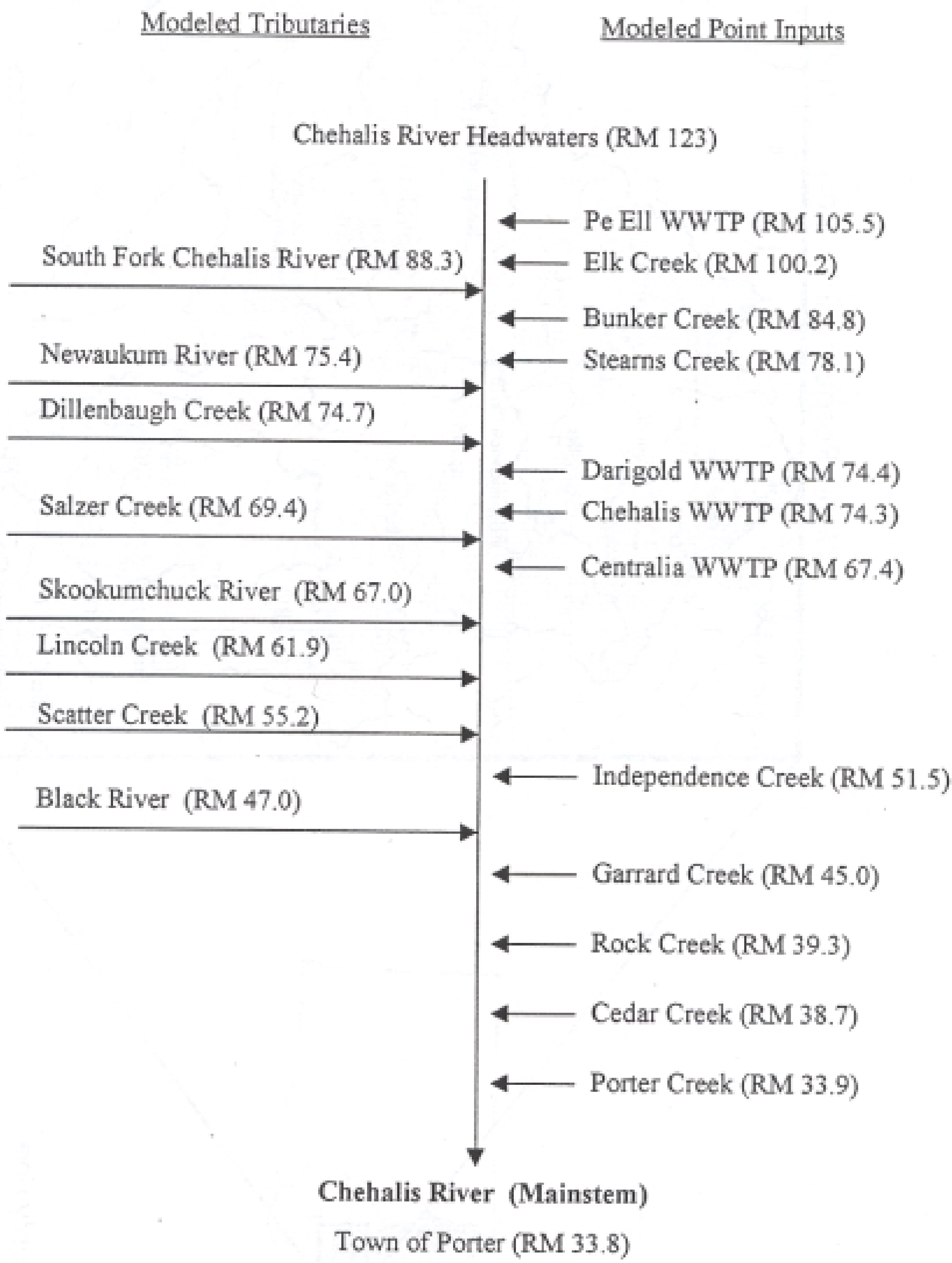


FIGURE 1

Figure 2. Schematic of the Stream Network Model Geometry



Appendix A

Modeling Analysis Data

Table Al. Riparian Shade Data used for Model Calibration and Validation

Stream Segment Name .	Median Width (ft)	Azimuth to due South (degrees)	Canopy Type	Riparian Canopy Type on Segment (%)	Modeled Shade for Canopy Type (%)	Overall Proportional Segment Shade (%)
Chehalis River Headwaters to Elk Creek	44	5°	Mid- Seral Conifer	31 %	68%	53%
			Early Seral Conifer	11%	57%	
			Hardwoods	42%	50%	
			Non-Forested Land	16%	30%	
Chehalis River Elk Creek to Newaukum River.	74	80°	Mid- Seral Conifer	6%	54%	18%
			Hardwoods	25%	23%	
			Non-Forested Land	69%	13%	
Chehalis River Newaukum River to Skookumchuck River	77	0°	Non-Forested Land	100%	22%	22%
Chehalis River Skookumchuck River. to Town of Porter	130	-50°	Mid- Seral Conifer	1%	43%	16%
			Early Seral Conifer	1%	28%	
			Hardwoods	44%	20%	
			Non-Forested Land	54%	12%	

Table Al. Continued Riparian Shade Data used for Model Calibration and Validation

Stream Segment Name .	Median Width (ft)	Azimuth to due South (degrees)	Canopy Type	Riparian Canopy Type on Segment	Modeled Shade for Canopy Type (%)	Overall Proportional Segment Shade (%)
Black River	43	55°	Mid- Seral Conifer	4%	69%	37%
			Early Seral Conifer	7%	56%	
			Hardwoods	27%	47%	
			Non-Forested Land	62%	28%	
Dillenbaugh Creek	- 5	-70°	Mid- Seral Conifer	3%	83%	64%
			Hardwoods	47%	80%	
			Non-Forested Land	50%	47%	
Lincoln Creek	10	90°	Mid- Seral Conifer	11%	83%	59%
			Early Seral Conifer	2% 0	80%	
			Hardwoods	22%	80%	
'			Non-Forested Land	65%	47%	
Newaukum River	15	-70°	Non-Forested Land	100%	43%	43%
Salzer Creek	6	-90°	Mid- Seral Conifer	3%	84%	68%
			Early Seral Conifer	1 %	81%	
			Hardwoods	56%	82%	
			Non-Forested Land	40%	48%	
Scatter Creek	12	85°	Mid- Seral Conifer	5%	82%	69%
.			Early Seral Conifer	6%	78%	
			Hardwoods	59%	78%	
			Non-Forested Land	30%	46%	

Table Al. Continued Riparian Shade Data used for Model Calibration and Validation

Stream Segment Name	Median Width (ft)	Azimuth to due South (degrees)	Canopy Type	Riparian Canopy Type on Segment	Modeled Shade for Canopy Type (%)	Overall Proportional Segment Shade (%)
South Fork Chehalis River	21	0°	Mid- Seral Conifer	9%	75%	52%
			Early Seral Conifer	3%	68%	
			Hardwoods	36%	65%	
			Non-Forested Land	52%	38%	
Skookumchuck River	22	70°	Mid- Seral Conifer	6%	78%	59%
			Early Seral Conifer	5%	71%	
			Hardwoods	57%	67%	
			Non-Forested Land	31%	39%	-

Table A2. Instream Flow and Temperature Data used for Model Calibration and Validation

Description of Location	Model Node Type	River Mile	Calibration (August 1991)		Validation (August 1992)	
			Modeled Flow (cfs) ①	Measured Temperature (°C) ③	Modeled Flow (cfs) ①	Measured Temperature (°C) ③
Pe Ell Wastewater Treatment Plant	Point	105.5	0.2	16.0 ⑧	0.1	15.6⑧
Elk Creek near Mouth	Point	100.2	29.0	14.7	29.9	17.2
South Fork Chehalis River near Mouth	Tributary	0	11.1	21.2	14.8	20.1
Chehalis River confluence with South Fork	Junction	88.3	66.3	20.1	66.1	19.7
Bunker Creek near Mouth	Point	84.8	1.3	15.2	0.3	17.5
Steams Creek near Mouth	Point	78.1	3.1	15.2	3.6	18.0
Newaukum River near Mouth	Tributary	0	48.4	20.9	46.4	20.4
Chehalis River confluence with Newaukum	Junction	75.4	109.0	22.7	106.2	22.2
Dillenbaugh Creek near Mouth	Tributary	0	1.4	18.8	1.3	18.6
Chehalis River confluence with Dillenbaugh	Junction	74.7	110.2	22.1	110.0	21.8
Darigold Wastewater Treatment Plant	Point	74.4	0.4	25.5 ⑧	0.6	23.2⑧
Chehalis Wastewater Treatment Plant	Point	74.3	1.9	25.5 ⑧	0.7	23.2⑧
Salzer Creek near Mouth	Tributary	0	2.8	19.2	0.5	18.2
Chehalis River confluence with Salzer	Junction	69.4.	125.8	20.2	111.0	24.4
Centralia Wastewater Treatment Plant	Point	67.4	2.3	24.2 ⑧	1.8	23.9⑧
Skookumchuck River modeled Headwater	Headwater	6.5	88.0 ⑤	14.9	54.0⑥	14.9④
Skookumchuck River near Mouth	Tributary	0	74.1	20.4	60.3	18.7
Chehalis River confl. with Skookumchuck ~	Junction	67.0	220.1	22.7	176.7	22.5

Table A2.Cohtinued. Instream Flow and Temperature Data used for Model Calibration and Validation

Description of Location	Model Node Type	River Mile	Calibration (August 1991)		Validation (August 1992)	
			Modeled Flow (cfs) ①	Measured Temperature (°C) ③	Modeled Flow (cfs) ②	Measured Temperature (°C) ③
Lincoln Creek near Mouth	Tributary	0	1.2	19.0	0.5	16.2
Chehalis River confluence with Lincoln	Junction	61.9	223.7	23.2	190.8	22.9
Scatter Creek near Mouth	Tributary	0	4.0	20.9	0.6	21.1
Chehalis River confluence with Scatter	Junction	55.2	297.7	21.3	203.9	20.8
Independence Creek near Mouth	Point	51.5	0.6	17.4	2.1	17.4④
Black River modeled Headwater ⑦	Headwater	15.3	18.5	16.0	22.9	16.2
Black River near Mouth	Tributary	0	66.4	21.0	51.0	18.7
Chehalis River confluence with Black	Junction	47.0	372.8	22.5	286.4	19.5
Garrard Creek near Mouth	Point	45.0	3.9	18.3	5.0	15.9
Rock Creek near Mouth	Point	39.3	2.6	14.7	3.2	14.7
Cedar Creek near Mouth	Point	38.7	13.9	14.9	2.9	15.0
Porter Creek near Mouth	Point	33.9	12.8	14.5	11.4	14.5④
Chehalis River at Town of Porter	End	33.8	412.6	19.8	312.8	21.2

① From Table C3 m Pickett (1994a)
② From Table G1 in Pickett (1994a)
③ From Tables D 1 and F 1 in Pickett (1994a). Mainstem temperature values used were the first downstream station measured from location of modeled node. Only surface temperatures were used where depth profile data were collected. The highest temperatures measured in the month were used if multiple dates were sampled.
④ Data from 1991 were used since no data were collected in 1992.
⑤ USGS measured flow was used from the same date (Aug. 27/91) as the temperature was measured
⑥ USGS measured flow was used from the same day (Aug 27th) ast the temperature measured the previous year.
⑦ From Pickett (1994b)
⑧ Used the temperature of the river since wastewater discharge temperatures were not measured.

Table A3. Riparian Shade Data Estimates of Passive Restoration Strategy

Stream Segment Name	Median Width (ft)	Azimuth to due South (degrees)	Canopy Type	Riparian Canopy Type on Segment	Modeled Shade for Canopy Type (%)	Overall Proportional Segment Shade (%)
Chehalis River - Headwaters to Elk Creek	44	5°	Late Seral Conifer	42%	72%	75%
			Late Seral Hardwoods	58%	77%	
Chehalis River - Elk Creek to Newaukum River	74	80°	Late Seral Conifer	6%	47%	53%
			Late Seral Hardwoods	94%	53%	
Chehalis River - Newaukum River to Skookumchuck River	77	0°	Late Seral Hardwoods	100%	64%	64%
Chehalis River - Skookumchuck River. to Town of Porter	130	-50°	Late Seral Conifer	2%	46%	47%
			Late Seral Hardwoods	98%	47%	

Table A3. Continued. Riparian Shade Estimates of Passive Restoration Strategy

Stream Segment Name	Median Width (ft)	Azimuth to due South (degrees)	Canopy Type	Riparian Canopy Type on Segment (%)	Modeled Shade for Canopy Type (%)	Overall Proportional Segment Shade (%)
Black River	43	55°	Late Seral Conifer	11%	71%	75%
			Late Seral Hardwoods	89%	76%	
Dillenbaugh Creek	5	-70°	Late Seral Conifer	3%	81%	85%
			Late Seral Hardwoods	97%	85%	
Lincoln Creek	10	90°	Late Seral Conifer	13%	80%	84%
			Late Seral Hardwoods	87%	85%	
Newaukum River	15	-70°	Late Seral Hardwoods -	100%	78%	78%
Salzer Creek	6	-90°	Late Seral Conifer	4%	83%	85%
			Late Seral Hardwoods	96%	85%	
Scatter Creek	12	85°	Late Seral Conifer	11%	82%	85%
			Late Seral Hardwoods	89%	85%.	
South Fork Chehalis River	21	0°	Late Seral Conifer	12%	78%	82%
			Late Seral Hardwoods	88%	83%	
Skookumchuck River	22	70°	Late Seral Conifer	11 %	76%	81%
			Late Seral Hardwood	89%	82%	

Appendix B

Previous TMDL Submittal

Additional Analysis for Upper Chehalis River Temperature TMDLs

Paul J. Pickett
Watershed Assessments Section
Environmental Investigations and Laboratory Services Program
Washington State Department of Ecology
January 23, 1997

Introduction

Twenty-one waterbodies in the upper Chehalis River basin (WRIA 23) were included as part of the Upper Chehalis Total Maximum Daily Load (TMDL) submitted to EPA (Table 1)[1]. Eleven waterbodies were included because they are listed as water-quality limited for temperature on Washington's 1994 303(d) list. The other ten were included as preventative TMDLs. Approval of the temperature TMDLs was placed on hold while the additional analysis presented
in this document was developed.

Chapter 173-201 A WAC, the state Water Quality Standards (WQS), require that water temperatures in Class A and AA waterbodies remain below 18 °C and 16 °C, respectively, unless caused by natural conditions. The waterbodies on the 303(d) list are all waters where temperatures above the state criteria were measured either as part of routine ambient monitoring or during the TMDL studies (Pickett, 1994a;b). Table 1 indicates the classification of each TMDL waterbody and whether the water body's TMDL is preventative or due to a 303(d) listing.

Sources of Temperature Impairment

A TMDL analysis requires evaluation of both point and nonpoint sources of pollution. Point sources of pollution must be evaluated for the thermal loading contributed to the receiving water by the effluent discharge. The impact of point sources on instream temperatures will depend on the temperature of the effluent and the amount of dilution. Treatment of the thermal loading as a conservative parameter within the mixing zone would be protective, since temperatures will tend to reach an equilibrium with the environment due to natural processes.

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[1] The original TMDL'submittal included waterbody WA-23-1050 (Skookumchuck River from Hanaford Creek to Bloody Run Creek). This was in error - the correct waterbody was WA-23-1030 (Skookumchuck River from mouth to Hanaford Creek). This is consistent both with the 1994 303(d) listing and the other elements of the Upper Chehalis TMDL listing.

The term "nonpoint pollution source" does not apply well to temperature problems, since the actual thermal loading source is the sun. The "nonpoint sources" that affect stream temperature are actually the human-caused alterations of watershed characteristics that allow increased heating of the stream from the sun and air.

The watershed characteristics affecting stream heating processes were reviewed in Sullivan et aL (1991). These characteristics fall into 4 general categories: geography, climate, stream channel and flow characteristics, and riparian shading. The first two categories are "given" and cannot be modified by human activity. Therefore, a temperature TMDL is by necessity limited to activities that improve stream temperatures through modification of stream channel and flow characteristics and through restoration of riparian shading.

Stream channel and flow characteristics consist of a number of elements that include stream velocity and depth, channel morphology, substrate composition, and water clarity.

Stream velocity and depth affect temperature through changes in the heat transfer rate and thermal mass of the waterbody. Deeper water provides a greater volume of water, so that thermal loading will increase temperature more slowly. However slow velocities will allow more time for heat transfer to have an effect. Shallower water will increase the heating of the substrate and- the overall heat transfer rate. Reduced flow or changes in the channel that result in a stream becoming slower or shallower will likely contribute to increased heating of the stream.

Human activities can alter stream depth and velocities in many ways. Channel morphology is in a dynamic equilibrium with geologic processes. If human activities increase the erosivity of the watershed, the bed load of sediment will increase. The higher bed load often results in a wider shallower channel that is more susceptible to heating from the air and sky. Another consequence would be that more of the stream flow could become inter-gravel flow, resulting in shallower surface flows. If sources of erosion in the watershed are reduced or eliminated, bed load could be reduced, allowing the stream to return to narrower, deeper, and swifter channel.

Low flows in the Chehalis basin coincide with dry, warm weather and the highest rates of water withdrawals. Increasing rates of water withdrawals, both from surface or from ground water, can have the direct effect of lower instream flows and increasing water temperatures during the dry season. Protection of minimum baseflows may depend on setting and enforcing limits on water withdrawals.

If suspended sediment loads have increased as a result of watershed degradation, temperatures may increase due to increased heat absorption by the sediments. In this situation, improvements in water clarity could result in lower water temperatures.

Riparian shading depends on mature multi-layered riparian vegetation. Maintaining a riparian buffer zone with mature vegetation has been widely identified as the most important requirement for ensuring lower stream temperatures. The effectiveness of improving and maintaining the riparian canopy depends on the how much the "view to the sky" is reduced. The distance downstream that the effect of shading is felt is a function of altitude and the stream flow characteristics. However in almost every case increased shading from riparian vegetation will help increase stream temperatures.
In summary, sources of temperature impairment in the Upper Chehalis basin can be categorized as follows:

- Point sources;
- Riparian vegetation degradation;
- Erosion and sediment load; and
- Low instream flows.

Identification of Specific Sources

Point Sources

There are a number of permitted point source discharges to the TMDL waterbodies. The aquaculture discharges in the Chehalis basin have effluent temperature well below the water quality criteria, so these sources are not considered significant. The rest of the permitted discharges in the Chehalis basin have effluent temperatures that merit review of their impact on receiving waters.

Riparian Vegetation, Erosion, and Sediment Load

In 1991 and 1992, as part of the Chehalis Fishery Restoration Program, the U.S. Fish and Wildlife Service (USFWS) conducted an extensive survey of sources of fishery habitat degradation (Wampler, et aL, 1993). The survey measured a wide variety of degradation types, many of which probably contribute to temperature problems in the TMDL waterbodies. The survey specified impacts as due to agricultural, logging, or other causes where they could be identified. Specific problems were identified such as vehicle access to the stream, gravel removal, construction impacts, eroded banks, livestock access, pollutant inputs and water withdrawals. These degradations were entered into a Geographic Information System (GIS) database, and have been mapped for the entire basin.

To evaluate measured degradations that affect stream temperatures, selected USFWS data from Wampler et al. (1993) were grouped into 4 categories: reduced tree canopy, riparian vegetation loss, observed excess bed sediment load, and bank erosion. For data summary and mapping, USFWS grouped the stream and river systems into larger sub-basins. Table 1 shows the TMDL waterbodies with the associated USFWS sub-basins, and the measured degradations found in each sub-basin. The data is organized by the 4 categories, and presented in terms of stream miles of degradation and the percent of total miles surveyed. Table 2 provides descriptions of the degradation sources in each category.

Table 1 illustrates that significant watershed restoration is needed for every watershed that includes TMDL waterbody. With the sole exception of Cedar Creek, all these waterbodies require restoration of stream canopy and riparian vegetation for at least 20% to over 90% of stream miles. Most streams also show severe bed sediment or erosion problems.

Water Clarity

To evaluate water clarity as 8 factor in high stream temperatures, data from the Chehalis dry season TMDL studies (Pickett, 1994a;b) were evaluated to compare temperature to turbidity levels. Figure 1 illustrates the relationship between these two parameters in the Chehalis basin. Clearly, high turbidity levels were only associated with low water temperatures, and during periods of high temperatures turbidity was generally low. Therefore, a lack of water clarity does not appear to be a factor in high water temperatures.

Low Instream Flows

In the upper Chehalis basin low stream flows have been identified as a widespread problem. Water resources investigators at Ecology conducted a Water Resources Assessment for the upper Chehalis (Wildrick, 1995), which found declining trends in mainstem river gages. Water resources in the basin appear to be overallocated by over 200%. Instream flows have been falling below regulatory minimum levels at an increasing rate in waterbodies throughout the basin. Therefore, low flows must be considered a possible contributing factor to observed temperature problems.

Natural Conditions

It is possible that in some areas of the Chehalis basin, "natural" water temperature conditions (conditions in the absence of anthropogenic impacts) are above the water quality criteria. However, human-caused impacts to the watershed are widespread and no evidence is available to show where natural conditions may exceed criteria. Even if in the future natural conditions were found to be above criteria in any waterbodies, protection of stream temperatures will still be required both to prevent degradation and as a preventative TMDL.

TMDL Goals and Targets

The goal of the TMDL for temperature in the upper Chehalis basin is to meet the state water quality criteria in each TMDL waterbody, and to prevent the degradation of temperature levels in the TMDL waterbodies where criteria are being met or natural conditions are above criteria. The TMDL goals will be met by control of the sources that impact waterbody temperatures, and targets will be established for source controls. These targets will constitute the Load Allocations and Wasteload Allocations for this TMDL.

Point Sources

Permitted discharges in the Chehalis basin have temperature impacts routinely reviewed as part of their NPIDES permits. The permit for the Pacific Power discharge to Hanaford Creek in the Skookumchuck basin requires the removal of the discharge when stream temperatures are elevated. For the rest of the discharges the possible impacts of thermal loading have been evaluated, and Ecology has determined that they will not contribute to temperature problems in the receiving water. When these permits are renewed, and for any new discharge or change in an existing discharge, the impacts on the receiving water will be reviewed for compliance with the temperature TMDL. The targets for permitted discharges will be to meet temperature water quality standards at the edge of the regulatory mixing zone.

Riparian Vegetation, Erosion, and Sediment Load

In general, targets for watershed restoration will be based on USFWS degradation study. For correction of riparian vegetation and canopy loss, erosion, and bed sediment loads, the levels identified in Table 1 will serve as sub-basin targets. Site-specific data to guide restoration efforts is provided in the GIS database for the USFWS degradation study.

Low Instream Flows

Targets for instream flows shall be those established by Ecology's Water Resources and Shoreline Management Program, who rely on the analysis in Wildrick et al. (1995), the results of Instream Flow Incremental Method (IFIM) studies, and compliance with the regulatory requirements of WAC 173-522-020.

Margin of Safety

A margin of safety (MOS) is required as part of this TMDL to ensure that the TMDL is sufficiently protective. The conditions that determine water temperatures in the natural environment are understood in general terms, but the site-specific effectiveness of source controls for temperature are difficult to determine with certainty. For any specific location, the source controls described for the TMDL will vary in their effectiveness and in their impact on downstream areas.

The TMDL waterbodies tributary to the mainstem represent only the farthest downstream portions of their watersheds. To ensure a MOS, controls will be applied to identified sources throughout the watershed for each TMDL waterbody tributary to the mainstem and along all TMDL segments of the mainstem. The USFWS degradation study will be used as a guide, but if other sources are discovered they will be also be subject to source controls.

Implementation Considerations

Implementation will be through the mechanisms identified in the Nonpoint Source Implementation Plan provided in the original TMDL submittal. Ongoing activities include: the USFWS Chehalis Fishery Restoration Program;. Watershed Analyses under the TFW program; watershed restoration by the Tribes and Conservation Districts in the basin; county issuance of Shoreline permits; Ecology technical assistance, grant funding and enforcement; and implementation of the Chehalis Watershed Plan and the "Shade the Chehalis" program by the Chehalis River Council.

Watershed restoration was also recommended for implementation of the nonpoint source load allocations for the upper Chehalis BOD and ammonia TMDLs. Although the focus of BOD and ammonia source controls may be somewhat different than for temperature source controls, there is likely to be a lot of overlap. In many cases watershed restoration activities can be integrated .to benefit all parameters covered by TMDLs in the upper Chehalis basin as well as other habitat degradation problems.

Implementation of base flow protections will by through Ecology's Water Resources and Shoreline Management Program. Ecology is committed to maintaining minimum baseflows, as evidenced by recent decisions to deny applications for new surface and ground water right permits in the upper Chehalis Basin.

Monitoring will continue to determine the effectiveness of the upper Chehalis temperature TMDLs. Monitoring activities by Ecology will be guided by the 5- year Watershed Approach. On-going monitoring include Ecology's ambient monitoring, Best Management Practices (BMP) evaluation monitoring funded by Ecology and the USFWS, monitoring by the Chehalis Tribe, and monitoring as part of other BMP and watershed restoration projects by the counties and CDs.

References

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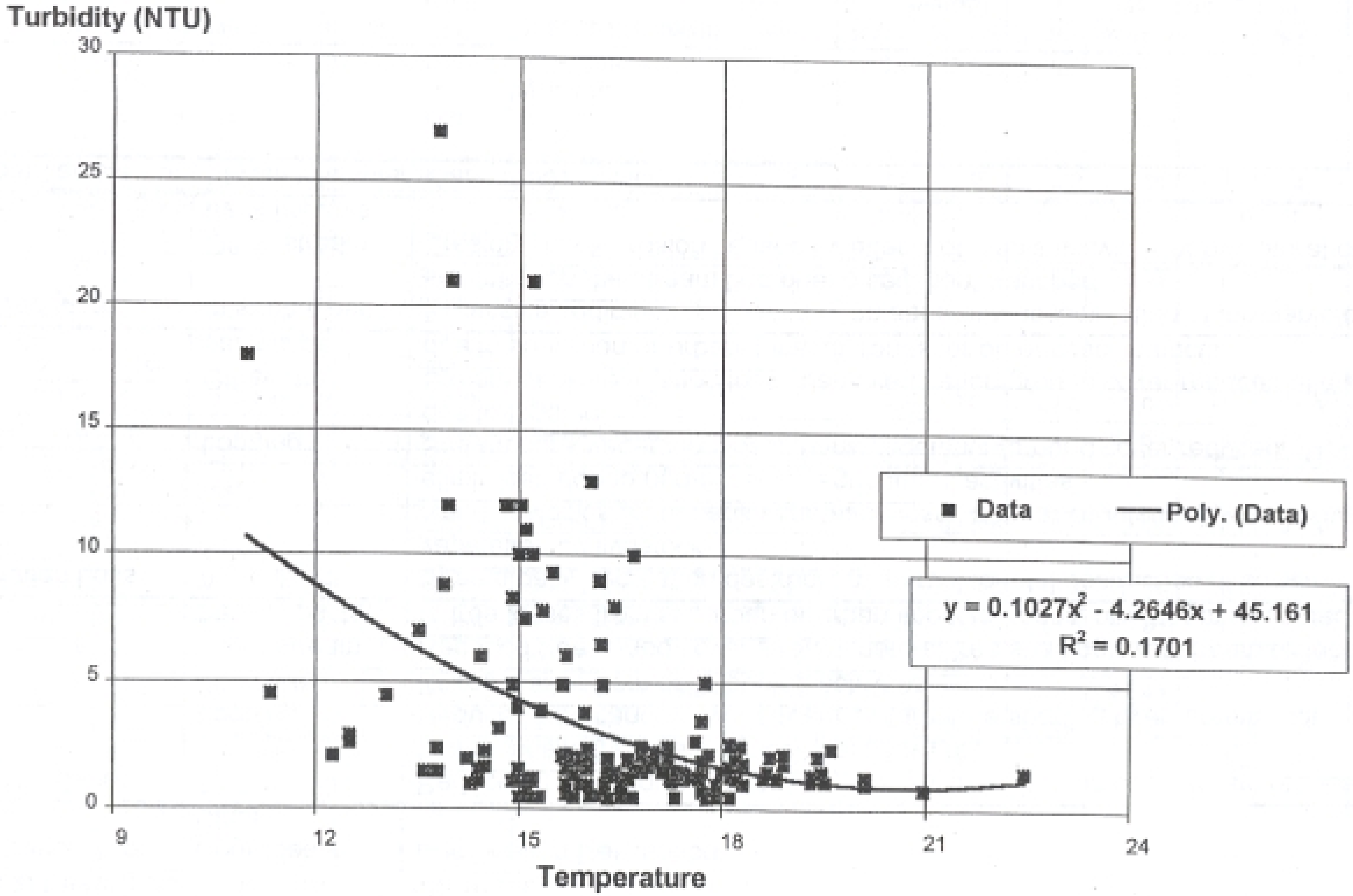
Table 1. Temperature TMDL Waterbodies and Degradation Sources

WRIA	Waterbody name	Class	Listed or Preven-tafive?	USFWS Sub-basin	Survey Stream Miles	Observed Sources of Degradation: Red. Canopy		Veg. Loss		Bed Sediment		Erosion	
						miles	%. srvy	miles	% srvy	miles	% srvy	miles	% srvy
WA=23-1010	Chehalis R (Porter to Scammon	A	Listed	Upper Chehalis Mainstem	28	10.4	37.1 %	8.7	23.8%	0.0	0.1 %	7.8	27.7%
WA-23-1020	Chehalis R (Scammon to Newaukum)	A	Listed										
WA-23-1012	Cedar Creek	A	Prevent	Gibson Creek	38	2.5	6.6%	2.2	5.8%	1.6	4.2%	0.6	1.5%
WA-23-1013	Rock Creek	A	Prevent	Rock Creek	53	6.4	12.0%	12.2	23.1%	9.6	18.1 %	11.5	21.7%
WA-23-1014	Garrard Creek	A	Prevent										
WA-23-1015	Black River	A	Listed	Black River	88	26.1	29.7%	24.6	28.0%	9.4	10.7%	7.2	8.2%
WA-23-2010	Mima Creek	A	Prevent										
WA-23-2020	Beaver Creek (Black)	A	Prevent										
WA-23-2121	Littlerock Ditch	A	Prevent										
WA-23-1017	Independence Creek	A	Prevent	Lincoln Creek	63	5.2	8.2%	24.6	39.0%,	11.7	18.6%	14.4	22.9%
WA-23-1018	Scatter Creek	A	Listed	Scatter Creek	31	18.7	60.2%	16.3	52.8%	8.5	27:3%	0.9	2.9%
WA-23-1030	Skookumchuck R Mouth to Hanaford	A	Listed	Skookumchuck River	110	70.2	63.8%	39.6	36.0%	30.0	27.2%	20.8	18.9%
WA-23-1023	Salzer Creek	A	Listed	China Creek	37	34.2	92.5%	23.0	62.1 %	16.8	45.3%	3.6	9.6%
WA-23-1027	Dillenbaugh Creek	A	Listed										
WA-23-1070	Newaukum R	A	Listed	Newaukum River	125	28.3	22.6%	50.4	40.3%	9.0	7.2%	28.8	23.0%
WA-23-1102	Steams Creek	A	Prevent	Steams Creek	20	1.2	6.1 %	18.0	90.0%	0.8	3.8%	11.8	59.0%
WA 23-1104	Bunker Creek	A	Prevent.	Scammon Creek	47	6.2	13.2%	29.2	62.2%	8.8	18.7%	22.9	48.8%
WA-23-1108	South Fork Chehalls R	A	Lifted	South Fork Chehalis	113	38.8	$1.7%	47.9	42.4°/a	37.2	33.0%	55.9	49.4%
WA-44-1108	Elk Creek	A	Prevent	Elk Creek	43	11.6	27.0%	5.5	12.7%	9:9	22.9%	27.7	64.3%
WA-23-1100	Chehdlis R (Newaukum to Rack	A	Listed	Crim/Rock Creeks	42	6.3	15.1%	13.6	32,4%	1.2	2.9%	19.6	46.8%
WA-23-1110	Chehalis River (Rock to F/W Forks	AA	Listed										

Table 2. Description of Degradation Sources		
Degradation Type[1]	Degradation Class[2] .	Degradation Description[2]
Reduced Canopy	Agricultural	Reduced tree canopy over stream: natural tree shading over stream reduced due
		to tree losses from past agricultural activities.
	Logging	Reduced-tree canopy over stream: natural tree shading over stream reduced due
		to tree losses from past logging activities.
	Other stream	Reduced tree canopy over stream: natural tree shading over stream reduced due
	bank impacts	to tree losses from suburban or urban impacts, roads, or other mist: impacts.-
Vegetation Loss	Agricultural	Stream bank vegetation destruction: partial to total destruction of stream bank
		vegetation by livestock.
	.	Non-livestock stream bank vegetation loss: natural vegetation/ground cover
		eliminated due to non-livestock agricultural activities. .
	Logging	Stream bank vegetation loss: bank vegetation/ground cover reduced/eliminated
		due to logging.
	Other stream	Stream bank vegetation logs: bank vegetation/ground, cover reduced/eliminated
	bank impacts	due to suburban or urban impacts, roads, or other misc. impacts.
Bed Sediment	In stream bed	Excessive sediment: ,presence of an abnormal accumulation of inorganic/organic
		sediment on the stream bad due to sediment transport
Erosion.	Other stream	Erosion: bank erosion caused by effects of man's activities or by natural causes.
	bank impacts	

1 From Table 1
2 From Wampler et al. (1993)

Figure 1. Upper Chehalis Temperatures and Turbidity



Appendix C

Public Notice Materials

STATE OF WASHINGTON

DEPARTMENT OF ECOLOGY

P.O. Box 47775 • Olympia, Washington 98504-7775 • (360) 407-6300

APRIL 28, 1999

PUBLIC COMMENT PERIOD ON WATER TEMPERATURE STRATEGY FOR THE UPPER CHEHALIS RIVER

Water temperatures in many areas of the Upper Chehalis River Watershed (WRIA 23) have become too warm during the dry summer months to sustain all the expected life-cycle stages of cold water fish (salmon, steelhead, and trout).

This is a violation of state water quality standards. The Federal Clean Water Act requires the state to develop strategies to reverse these conditions and restore temperatures to levels that will sustain the cold water fish that still survive in the Upper Chehalis River system.

The Department of Ecology has developed a draft Total Maximum Daily Load (TMDL) for water temperature in the Upper Chehalis River (WRIA 23). This study evaluates water temperatures and makes recommendations about what must be done to reduce those temperatures to levels that will sustain all life-cycle stages of cold water fish.

The study proposes to reduce water temperatures to acceptable levels over time by restoring riparian zone shade.

The public is invited to comment on this draft study until June 4, 1999. An electronic copy of the draft Upper Chehalis River Basin Temperature TMDL may be obtained by E-mailing Kahle Jennings at kjen461@ecy.wa.gov. To obtain a paper copy of the TMDL, contact Cathy Brockmann at 407-6270.

Written comments should be postmarked no later than June 4, 1999 and mailed to:

Kahle Jennings
Department of Ecology, Southwest Regional Office
P.O. Box 47775
Olympia, WA 98504-7775

Comments will also be accepted through electronic mail at kjen461@ecy.wa.gov through June 4, 1999. For further information call (360) 407-6269

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Heidi Hotson, says that she is the legal clerk of

The Chronicle

a daily newspaper, which has been established, published in the English language, and circulated continuously as a daily newspaper in the City of Centralia, and in said County and State, and of general circulation in said county for more than six (6) months prior to the date of the first publication of the Notice hereto attached, and that the said Chronicle was on the 7th day of July 1941, approved as a legal newspaper by the Superior Court of said Lewis County.

And that the attached is a true copy and was published in regular issues (and not in supplement form) of said newspaper as Legal # 0527,

once each day for a period of one

consecutive day,

commencing on the

4 day of May, 1999

and ending on the

4 day of May, 1999, and both dates inclusive, and that such newspaper was regularly distributed to its subscribers during all of said period. That the full amount of the fee charged for the foregoing publication is the sum of

$ 42.65.

Heidi Hotson

Subscribed and sworn to before me this

7 day of May, 1999.

Linda K Stewart

Notary Public in and for the State of Washington, residing at

Centralia

PUBLIC COMMENT PERIOD ON WATER TEMPERATURE STRATEGY FOR THE UPPER CHEHALIS RIVER

Water temperatures in many areas of the Upper Chehalis River Watershed (WRIA 23) have become too warm during the dry summer months to sustain all the expected life-cycle stages of cold water fish (salmon, steelhead, and trout).

This is a violation of state water quality standards. The Federal Clean Water Act requires the state to develop strategies to reverse these conditions and restore temperatures to levels that will sustain the cold water fish that still survive in the Upper Chehalis River system.

The Department of Ecology has developed a draft Total Maximum Daily Load (TMDL) for water temperature in the Upper Chehalis River (WRIA 23). This study evaluates water temperature and makes recommendations about what must be done to reduce those temperatures to levels that will sustain all life-cycle stages of cold water fish.

The study proposes to reduce water temperatures to acceptable levels over time by restoring riparian zone shade.

The public is invited to comment on this draft study until June 4, 1999. An electronic copy of the draft Upper Chehalis River Basin Temperature TMDL may be obtained by emailing Kahle Jennings at kjen461@ecy.wa.gov. To obtain a paper copy of the TMDL, contact Cathy Brockmann at 407-6270.

Written comments should be postmarked no later than June 4, 1999 and mailed to

Kahle Jennings
Department of Ecology
Southwest Regional Office
P.O. Box 47775
Olympia, WA 98504-7775

Comments will also be accepted through electronic mail at kjen461@ecy.wa.gov through June 4, 1999.

For further information call (360) 407-6269

L#0527 May 4, 1999

Legal # 9244

Affidavit of Publication

STATE OF WASHINGTON
County of Thurston County
ss.

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Publish: May 4, 1999

The undersigned being first duly sworn on oath deposed and says: That she is the Principal Clerk of The Olympian which is a legal newspaper printed and published in the City of Olympia, Thurston County, Washington: of general circulation in said City, County and State; that the request for public comment in the case of water temperature strategy for the upper Chehalis River of which the attached is a printed copy, was published in said newspaper:

On the 4th day of May 1999
the ______ day of ______ 1999
the ______ day of ______ 1999
the ______ day of ______ 1999
the ______ day of ______ 1999
the ______ day of ______ 1999
the ______ day of ______ 1999

that the said newspaper was generally circulated during all of said time, and has been published for more than six months prior to the dates of the publication of this legal document, and that said notice was published in the newspaper proper and not in supplement form.

The amount of fee charged for this publication $86.88

Ruth Richard
Principal Clerk

Subscribed and sworn to me this 4th day of May 1999.

MARTHA L. HOGAN
NOTARY PUBLIC
COMMISSION EXPIRES MARCH 18, 2001
STATE OF WASHINGTON

Martha L Hogan
Notary Public and for the State of Washington residing at Olympia, Thurston County, Washington

The Olympian has been appointed as a legal newspaper by order of the Superior Court of the State of Washington for Thurston County, dated July 10, 1941, in the county in which said newspaper is published in accordance with RCW 65.16.020 and RCW 63.16.040.

Note - The above affidavit and fee is in compliance with RCW 63.16.030 and Sec. 3, Chapter 34, Laws of 1977.

Printed from CRC Website

Chehalis River In Hot Water:
Temperature Control Strategy Developed for the Upper Chehalis River

Water temperatures in some areas of the Upper Chehalis River Watershed (WR IA 23) have become so warm during June and July that it can not support all the life-cycle stages of cold water fish (salmon, steelhead, and trout). In some cases, the temperatures are so warm that they can be lethal for these species.

Under the Clean Water Act, every state has its own standards designed to protect water quality. Most of the upper Chehalis River is classified in the State Water Quality Standards as Class "A" waters. Class "A" waters should support migration, rearing, and spawning of cold water fish species. Temperatures in these waters should not be warmer than 18.0 degrees C (64.4 degrees Fahrenheit). When natural river conditions cause the temperature to exceed 18.0 degrees C, no temperature increases due to human activities can be allowed that will raise the receiving water temperature by greater than 0.3 degrees C.

Water quality monitoring shows that temperature criteria are exceeded in at least 19 segments of 9 different streams in the upper Chehalis River watershed. The following streams are included on Washington State's 1998 Section 303(d) list of impaired waters because portions of them violate the temperature criteria of the State Water Quality Standards:

- Black River
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- Chehalis River, South Fork
- Dillenbaugh Creek Lincoln Creek
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Temperature data collected in the Upper Chehalis River Basin show a definite pattern of seasonal variation. Most of the year temperature criteria are met. The critical period for temperature in the Upper Chehalis River Basin is in the months of June and July.

When a lake, river or stream fails to meet water quality standards the Federal Clean Water Act requires that the state place the water body on a list of "impaired" waters, and that an analysis called a Total Maximum Daily Load (TMDL) be prepared. A TMDL evaluates the water quality problem and the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the water body and still meet standards. The goal of a TMDL is to ensure the impaired water will attain water quality standards so that is supports designated beneficial uses.

THE UPPER CHEHALIS RIVER TEMPERATURE TMODL

The Upper Chehalis River TMDL has been developed for heat (i.e. incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. Heat generated by the amount of solar radiation from sunlight reaching the stream provides energy that raises water temperatures. A decrease in shade is the result of a lack of adequate riparian vegetation and causes a subsequent increase in solar radiation and thermal load. Human activities that contribute to degraded riparian vegetation conditions include agricultural activities, residential and urban development, and silvicultural activities. The Upper Chehalis River temperature TMDL establishes goals for a shade as a surrogate measure for incoming solar radiation. This study found over 30% of riparian vegetation has been lost or reduced in the upper basin.

Two other factors that influence the distribution of heat are assessed in the study: instrearn flow and channel morphology. Low flows may contribute to high temperatures by reducing the volume of water that can absorb incoming heat. Channel shape and condition may also influence heat distribution. With increased sediment loads, stream channels may become wider and shallower allowing more thermal radiation to be absorbed by the water surface.

The Upper Chehalis River system has had baseflows established for the protection of instream uses (e.g. salmonid habitat) at 14 locations by state rule. Recent assessments of compliance with that rule show that streams are not meeting these flows between 33 to 77 days pe ryear. The water rights and claims exceed the critical lowflow conditions (7QIO) by 400%.

Both of the additional factors evaluated, instream flow and channel morphology, had an important effect on stream temperatures. However, neither will be used in setting load allocations. The significant issue of over-allocation of the instream flow resources will be difficult to solve short of court adjudication. The strewn morphology that is not considered good for anadromous; fish habitat cannot be quantitatively linked to a manageable pollutant as required by EPA guidance for TN41DLs. Even if the sediment load were reduced enough to narrow the stream channel width, riparian vegetation would have to be introduced and grown to existing heights to achieve the results obtained by the modeling analysis.

It has been shown that managing riparian shading alone can achieve stream temperature standards. Therefore, the load allocation and implementation strategy will be based on restoring and maintaining riparian shade. If a future assessment can show a quantifiable link between sediment load and stream channel morphology, the TMDL may be revised to trade allocations between the shade measure established and sediment management practices. Likewise, if water rights can be returned to the river through conservation or adjudication, the TMDL may be revised to trade allocations between the shade measure established and the higher flows.

IMPLEMENTATION STRATEGY

The modeling results and the loading capacity show that existing shade levels are not sufficient to meet stream temperature standards throughout the Upper Chehalis River Basin. First, the existing riparian vegetation must be maintained. In addition, some sort of restoration will be needed to achieve the shade levels set as load allocations.

The passive restoration strategy involves the protection of existing riparian areas as. reserves combined with some silvicultural work to reach the existing vegetative potential rapidly. The strategy would be to allow existing species to attain old growth stage without species replacement. For existing confers at an average site index of 100, that would be a Western Hemlock dominated forest of 200 years with a height of 125feet. For existing hardwoods at an average site index of 100, that would be a Red Alder dominated forest of 60 years with a height of 100feet. The results of a passive restoration approach would be that all listed segments would meet temperature standards by the time existing vegetation reached old growth stage.

Even though passive restoration has been shown to eventually meet standards, active tree planting must still be conducted so that all riparian corridors have riparian shade. The model assumed that non-forested land uses had a 50% density of hardwoods. The passive restoration assumed that this increased to 85% density. This means that reaches that are now devoid of trees should be planted to help achieve the higher densilyfor these lands.

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This page created and maintained by Chehalis River Council

Kahle Jennings
Dept. of Ecology - Water Quality
P.O. Box 47775
Olympia, WA 98504

"...promote the conservation and restoration of the greater Chehalis River Basin Resources"

DROPS OF WATER

A monthly publication of the Chehalis River Council and Cooperating Partners.
Distributed without charge to newspaper readers throughout the Chehalis Watershed.
Issue 31 - June 1999

Chehalis River in Hot Water

Temperature control strategy developed for the Upper Chehalis River

Kahle Jennings, Wa. Dept of Ecology

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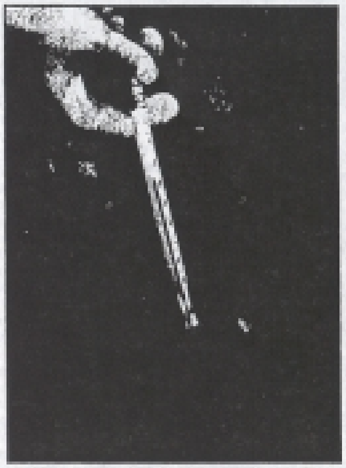

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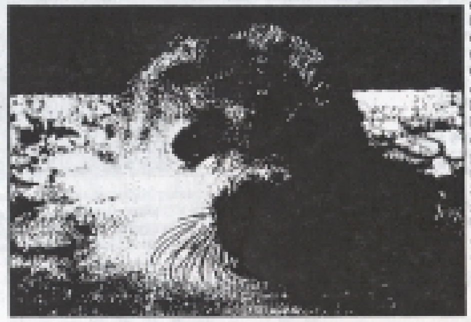
Continued on back page

Seals, Sea Lions, and Salmon

Mike Kelly, U.S. Fish and Wildlife Service

At just about every public presentation I've given recently, this question comes up: Why aren't we doing anything to stop seals from eating salmon? I never have a good answer, so I've decided to do some digging and find out what the story is. Besides, what better way to find out if anyone reads my little articles than to maybe generate a few phone calls with a controversial topic?



Luckily, I didn't have to dig too far. The National Marine Fisheries Service document cited below summarizes pretty much everything that the federal government, local agencies, and other entities know about the topic. The report describes feeding habits, behavior, known impacts, ecological considerations, information gaps, and describes some specific attempts to control predation by seals and sea lions. Most of what I say comes either from this report, or from recent newspaper accounts. You can view the report on-line at:
http://www.nwfsc.noaa.gov/pubs/tm/tm28/tm28.htm#toc

Obviously, the federal government is considering the issue. Officials are looking at the issue, especially with recent Endangered Species Act listings for salmon, and increasing populations of seals and sea lions. The report states: In the 1994 Amendments to the Marine Mammal Protection Act, Congress directed that a scientific investigation be conducted to "determine whether California sea lions and Pacific harbor seals a) are having a significant negative impact on the recovery of Salmonid fishery stocks which have been listed as endangered species or threatened species under the Endangered Species Act . . . , or which the Secretary finds are approaching such endangered species or threatened species status; or b) are having broader impacts on the coastal ecosystems of Washington, Oregon, and California." It is the results of this investigation that make up the report.

The amendments to the Marine Mammal Protection Act also made it possible, under very strict conditions, for states to "lethally remove" problem seals and sea lions. These conditions were met at the Ballard Locks in Seattle, however no sea lions have yet

Continued on back page

Water Quality: Field and Laboratory Methods

Rob Schanz, Chehalis River Council

The following is the second in a series of lessons

curate methods often cost a lot. It is important to un-

Wet weather septic system checks

Chehalis River... *continued from front page*

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Water Quality: Field... *continued from front page*

imprecise and inaccurate for detailed scientific stud-

iform bacteria, nitrates, phosphates, metals, pesti-

Conservation Easements: Top Land Protection Tool

Janet Strong, Chehalis River Basin Land Trust

Local and regional land trusts nearly quadrupled the acreage they protected with conservation easements from 1988 to 1998, according to Land Trust Alliance's 1998 National Land Trust Census. As of 1998, local and regional land trusts held 7,392 conservation easements, protecting approximately 1.4 million acres, compared to just 290,000 acres protected in 1988. The 1998 figure represents a 378 percent increase compared to 1988.

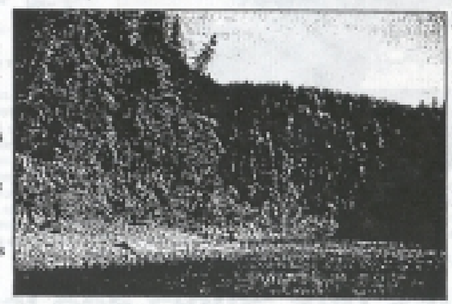
Those are the large figures and the future looks bright for the conservation of natural lands, but what does it mean for the individual landowner? Well, last year I donated a conservation easement on my seven acre forest next to my house. I would like to share some of my thoughts on why I did that. First of all, I enjoy my woods immensely. It is home to deer and elk, owls, pileated woodpeckers and songbirds, raccoons, mice, moles, squirrels and banana slugs. Several kinds of trees, shrubs and ground cover enrich it, especially in the spring when all is flowering. Each time I walk into it I see something I hadn't noticed before. It is home to me, too.

Much of the lands surrounding my forest have been logged and/or cleared. It stands there as valuable cover and living quarters for lots of creatures who no longer find enough habitat on the surrounding lands. And each year it gets a little closer to becoming a fully mature forest. I want it to keep right on growing into a more valuable wildlife sanctuary, ultimately into an old-growth parcel, well beyond my lifetime. So, I have entrusted its fate in the hands of the Chehalis River Basin Land Trust with a legally binding conservation easement. This document is filed with the county along with the deed and will "run with the land" as does any other easement. The easement limits what can be done with this seven acres to those activities which do no harm to the forest habitat and inhabitants. The land trust will ensure that these instructions are followed.

How do I feel about all this? Sure, I gave up the right to log it or turn it into pasture or to subdivide it. But, I feel good about knowing that my little forest, with all its varied features and residents, will stay a forest for a long, long time. I, and whoever lives here after me, will always be able to walk around in its cool shadows, listening to the tapping of the woodpecker, the chattering of the wren, following the new elk trails, admiring the flowers and the mosses and watching the growth and changes as it becomes a better and more interesting place to be.

Forests Offer Tree-mendous Benefits

Trees provide a host of benefits, even in urban areas, such as flood control, streambank stabilization, shading, wildlife habitat and pollution control just to name a few. Many benefits are quantifiable. Some examples:



Cities with an adequate urban forest can save 4 percent on heating costs and an additional 10 percent on cooling.

Deciduous trees provide shade and can save 10-30 percent on a single home's summer cooling costs.

Evergreen trees block winter winds and can save 20 percent on a home's winter heating needs.

One acre of trees can remove 40 tons of carbon dioxide, a gas that contributes to global warming, a year.

One acre of trees annually produces enough oxygen to sustain more than 1,000 people.

Trees reduce stormwater flow by intercepting rainwater on leaves, branches and trunks. Some of the intercepted water evaporates back into the atmosphere, and some soaks into the ground, thereby reducing the total amount of runoff that must be of water a day.

Retaining forest area and buffers has reduced stormwater costs in Fairfax County VA, by $57 million.

A single urban tree can provide the following economic benefits each year: air conditioning: $73; controlling erosion and storm water: $75; wildlife shelter: $75; and controlling air pollution: $50.

On average, trees add 5-7 percent to the value of a house lot.

Energy savings of 10 percent can result by increasing tree cover as little as 10 percent to buffers near buildings.

Trees provide $5.3 million in direct summer energy savings to residential homes in Dade County, FL. If live oaks were put in place of palms, those savings would increase 20 percent.

A single mature tree releases about 100 gallons of clean water vapor per day into the atmosphere and provides the cooling equivalent of nine room air conditioners operating at 8,000 BTUs per hour for 12 hours a day.

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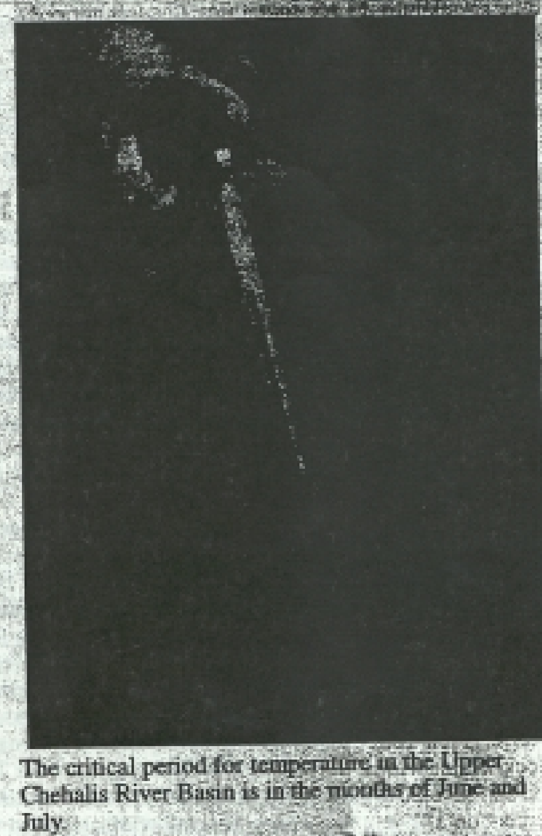

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Continued on back page

Chehalis River... *continued from front page*

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It has been shown that managing riparian shading alone can achieve stream temperature standards. Therefore, the load allocation and implementation strategy will be based on restoring and maintaining riparian shade. If a future assessment can show a quantifiable link between sediment load and stream channel morphology, the TMDL may be revised to trade allocations between the shade measure established and sediment management practices. Likewise, if water rights can be returned to the river through conservation or adjudication, the TMDL may be revised to trade allocations between the shade measure established and the higher flows.

IMPLEMENTATION STRATEGY

The modeling results and the loading capacity show that existing shade levels are not sufficient to meet stream temperature standards throughout the Upper Chehalis River Basin. First, the existing riparian vegetation must be maintained. In addition, some sort of restoration will be needed to achieve the shade levels set as load allocations.

The passive restoration strategy involves the protection of existing riparian areas as reserves combined with some silvicultural work to reach the existing vegetative potential rapidly. The strategy would be to allow existing species to attain old growth stage without species replacement. For existing confers at an average site index of 100, that would be a Western Hemlock dominated forest of 200 years with a height of 125 feet. For existing hardwoods at an average site index of 100, that would be a Red Alder dominated forest of 60 years with a height of 100 feet. The results of a passive restoration approach would be that all listed segments would meet temperature standards by the time existing vegetation reached old growth stage.

Even though passive restoration has been shown to eventually meet standards, active tree planting must still be conducted so that all riparian corridors have riparian shade. The model assumed that non-forested land uses had a 50% density of hardwoods. The passive restoration assumed that this increased to 85% density. This means that reaches that are now devoid of trees should be planted to help achieve the higher density for these lands.

The public is invited to comment on this draft study until June 4, 1999. An electronic copy of the draft Upper Chehalis River Basin Temperature TMDL may be obtained by E-mailing Kahle Jennings at kjen461@ecy.wa.gov. To obtain a paper copy of the TMDL, contact Cathy Brockmann at 407-6270.

Written comments should be postmarked no later than June 4, 1999 and mailed to:
Kahle Jennings
Department of Ecology,
Southwest Regional Office
P.O. Box 47775
Olympia, WA 98504-7775

Comments will also be accepted through electronic mail at kjen461@ecy.wa.gov through June 4, 1999.

For further information call (360) 407-6269

Water Quality: Field...*continued from front page*

Appendix D

Responses to Comments Received

Responsiveness Summary for the Proposed

Upper Chehalis River Basin Temperature TMDL

The public comment period for the proposed TMDL was opened on May 3, 1999. Notification was provided in the State Register and in two local newspapers. On June 3, a comment was received requesting that the comment period be extended. Ecology extended the comment period until June 11, 1999 by contacting all those who had requested a copy of the proposed TMDL. The following people provided comments:

I Molly Hemmen
Preston Gates & Ellis LLP
701 Fifth Ave, Suite 5000
Seattle, WA 98104-7078

2. Kevin Godbout
Weyerhaeuser
16703 SE McGillivray Blvd, Suite 220
Vancouver, WA 98683-3418

3. Dave Palmer
Chehalis River Council
PO Box 586
Oakville, WA 98568

4. Alan Henning
U.S. Environmental Protection Agency
1200 Sixth Ave
Seattle, WA 98 101

The following comments have been paraphrased to be more concise. The commentor number above is shown in parenthesis following each comment.

Comment: The wasteload allocation for the discharge from the Darigold plant should be determined with a sensitivity analysis of the model based on the maximum effluent temperature which results in no effect on river temperature. (1)

Response: The model was used in a sensitivity analysis and a different effluent temperature was established than originally proposed. The resulting wasteload allocation results in no predicted rise in river temperature.

Comment: An approach for determining the wasteload allocation based on a mixing zone analysis is proposed for the discharges of the cities of Centralia and Chehalis. (1)

Response: The analysis presented was flawed in the interpretation of the state water quality standards. Since the natural temperature of the river in the vicinity of the discharge is greater that the 18°C criterion, the maximum permissible temperature increase is 0.3°c, not the l.0°C figured by the formula. Also, the EPA policy is that unless certain reasonable assurances are provided concerning the success of the nonpoint source activities, then the required reductions must come from point sources. Since Ecology cannot provide these assurances, the wasteload allocations must be based on no predicted rise in river temperature. The model was used in a sensitivity analysis and a different effluent temperature was established than originally proposed. The resulting wasteload allocation results in no predicted rise in river temperature.

Comment: The wasteload allocations for temperature are not clearly set forth. (1)

Response: The specific discharge temperatures that represent the wasteload allocations have been clearly defined in a table and a new section added to the report describing how the wasteload allocations were set.

Comment: The conditions under which the TMDL applies are not clear. (1)

Response: The conditions of how the wasteload allocations apply have been clarified in the new section by an explicit description on the point of compliance and seasonal application. The wasteload allocations apply year-round and the at the point of discharge.

Comment: The point source permittees were not directly notified when the proposed TMDL became available for public notice, and therefore may be seriously prejudiced. (1)

Response: The public notification met the requirements of federal regulations. Notification of the proposed TMDL was announced in the State register and published in two local newspapers. When Ecology was informed that certain significant stakeholders had become aware of the proposed TMDL late, the comment period was extended to provide more time for an adequate response.

Comment: The permittees maintain and incorporate herein by reference, all procedural objections stated regarding the first temperature TMDL submittal to EPA in their comments to Ecology dated February 7, 1996. (1)

Response: The February 7, 1996 letter cited contains many technical objections related to the dissolved oxygen portion of the TNML Ecology submitted to EPA January 5, 1996 and procedural objections to the complete TMDL submittal, which included temperature. A review of the February 7, 1996 letter did not find any specific objections to technical issues related to the temperature portion of the January 5, 1996 TMDL submittal. The temperature portion of the January 5, 1996 TMDL submittal was withdrawn on September 24, 1997 when it became clear that EPA reservations about the temperature portion of the TMDL were delaying approval of the dissolved oxygen portion of the TMDL. Ecology has been working with the permittees to reconcile the procedural issues and accepts incorporating by reference the procedural objections raised in the February 7, 1996 letter to Ecology.

Comment: The watershed analyses conducted in the Upper Chehalis River Basin should be considered sufficient as an "other pollution control" under federal regulations where a TNML will not be required. Ecology had made this same policy determination for the watershed analysis conducted in the White River. To maintain consistent policy, Ecology should not establish the TMDL on the areas where watershed analyses have been completed.(2)

Response: EPA has verbally informed Ecology that the policy determination that the Upper White River watershed analysis and guidance document was not approvable under Section 303(d). EPA has verbally informed Ecology that the policy decision will be disapproved and that EPA will conduct a public process concerning the issue, among others. EPA has the mandatory final oversight on all decisions made by Ecology under Section 303(d).

Comment: The proposed TMDL described the agreement by Ecology and EPA that TMDLs will not be established on lands subjected to a forest practices proposal. During the public comment period, the agreement was passed in the legislature and codified in the "Forests and Fish" report.(2)

Response: The text of the TMDL has been updated to reflect the status of the legislation. In the TNML, the load allocations are specifically exempted from lands covered by this agreement and legislation.

Comment: Some of the model parameters used in the model vary a lot within a stream reach. This variance may affect model results.(2)

Response: It is well recognized that there is considerable variation in some model parameters within even small reaches of a stream. There is a lack of available information to establish model parameters with actual data for all reaches in the Upper Chehalis River Basin sufficiently to address this variability. Even if large amount of data were avail-able, the scale of the analysis conducted would prevent the fine level of segmentation that would accommodate this variability. The constant parameter values used were selected as typical oraverage conditions for each reach. The calibration served to adjust the remaining parameters to model actual response conditions. The validation served to check the model performance at prediction with an independent data set. In other words, the model parameters were set to predict a typical response for the system as a whole.

Comment: The method used to estimate several of the model state variables and parameters are poorly described, especially riparian shade, lateral inflow, stream width, and vegetation types. (2)

Response: The description of how these and other model inputs were developed has been expanded in the text of the TMDL report.

Comment: The model results of the proposed TMDL have an unacceptable error for use in a regulatory context. (2, 4)

Response: The model used for the proposed TMDL was re-calibrated and re-validated to improve model performance. A few of the assumptions made as part of the margin of safety (MOS)were removed because their application created problems with spatial bias in model predictions.

First, the MOS assumption that topographic shade is zero had a notable effect on predicting temperature in the upper reaches of the Chehalis River. With this MOS assumption, the model over predicted temperature beyond what could be compensated with calibration parameter sensitivities. Adding topographic shade to these upper reaches improved the performance of model prediction.

Second, the MOS assumption that only the surface temperature be used to represent observed conditions also had a spatial bias. The Centrailia reach area of the river deepens into pools and thermally stratifies. This is the only area of the model where surface temperatures are notably different than bottom temperature. Since the model is one- dimensional, it cannot predict the thermal stratification. To eliminate this bias, the volume-weighted temperatures were used as the observed temperatures for calibration and validation. Using volume-weighted temperatures improved the performance of the model prediction.

Finally, the question of acceptable model error must be viewed in terms of the MOS. The federal regulations describe TMDLs as "best estimates" and that allocations can be stated in terms of "gross allotments" (40 CFR 130.2(g)). Uncertainty in TMDLs is dealt with by establishing a MOS. The Upper Chehalis River Basin Temperature TMDL was developed with many conservative assumptions which results in a large MOS.

Comment: The proposed TMDL targets specific shade levels for streams. It is unclear whether an assessment was made to determine if the shade targets are achievable based on channel width and maximum tree height. (2)

Response: The TMDL shade allocations for each reach inciude assessments of widths measured by Ecology (Pickett, 1994a&b) and tree heights derived from regional growth curves (Henderson et al. 1989). Estimated achievable shade for each reach has been added to Table I I in the final TMDL report.

Comment: The proposed TMDL assumes that achieving shade targets alone will meet standards. Other factors that may also affect temperature, such as warm inflow ditches, were not assessed. (2,4)

Response: The proposed TMDL did assess the affect of flow and channel morphology on resulting temperatures. This assessment showed that these factors definitely had an affect on temperature, but that water quality standards could be achieved by only managing shade. However, the re-calibration of the model along with removal of additional human factors to estimate natural conditions changed the assessment for the final TMDL. With the new analysis, it has been shown that three streams tributary to the Chehalis River need to be managed to return to normal channel morphology. In addition, narrative load allocations have been added to establish targets for all waters tributary to those reaches modeled. This includes the allocation that effects of tributary ditches and groundwater on temperature must not be further exacerbated.

Comment: The use of a width to depth ratio of 10 as a benchmark is flawed. The geomorphic literature shows that under natural conditions the width to depth ratios can be greater and highly variable. (2)

Response: The TMDL uses the width to depth ratio of 10 as proposed for anadromous fish by the US Forest Service only as a threshold to test the sensitivity of the model for temperature predictions. When assessing the natural conditions of a stream, the mean width to depth ratio measured by Rosgen (1996) for the specific channel type was used. While it is recognized that these ratios can be highly variable, on averaging the entire reach the mean values should represent typical undisturbed conditions. The model predicts the temperature from the average conditions along the entire reach.

Comment: The assumptions used to establish the margin of safety weigh heavily on the model predictions. Is a MOS needed? Why make the conservative assumptions instead on trying to predict realistic numbers? (2)

Response: The margin of safety is a required element of the TMDL as defined in the statute. There are two ways to establish a MOS. First, an inherent MOS can be established through the use of conservative assumptions in the modeling analysis.

Second, an explicit MOS can be established as a matter of policy as a specific allocation. In practice, Ecology has used the inherent MOS for the previous TMDLs developed. In the proposed Upper Chehalis River Basin Temperature TMDL, a few of the assumptions made for the MOS proved to be biased and affected the model performance. These have been removed for the final to provide results closer to observed values.

Comment: It is not clear how the vegetation deficits presented from the U.S. Fish and Wildlife study (Wampler et al. 1993) relate to the shade increases required in the shade load allocations. (3)

Response: The data from the U.S. Fish and Wildlife study was just presented as background where riparian vegetation measurements have been made. The riparian shade load allocations and the riparian vegetation observed data were developed by different means and are not directly comparable. First, the shade load allocations are based on modeling of the entire reach, whereas the observations in the U.S. Fish and Wildlife study were based only on that portion surveyed. Second, the metrics of the two values are also different. The shade load allocations represent the amount of solar radiation blocked by riparian vegetation, which can be observed using tools such as a densiometer or solar pathfinder. The U.S. Fish and Wildlife study used stream walks where degraded riparian condition was observed and rated based on the best professional judgement of the survey team. No specific measurements of riparian canopy shade were recorded.

Comment: The proposed T@ML does not specify the amount of time required for all segments to reach old growth stage. (3)

Response: Each reach contains riparian vegetation that covers several different seral stages. Using the assumptions made on the average age of each of the seral stages defined in the GIS coverage used (canopy93), one can estimate the maximum time it would take for all riparian vegetation to reach later seral stage. A new table has been added to the final TMDL which estimates the time for each modeled reach to achieve a full seral stage of the existing riparian vegetation.

Comment: The TMDL should better spell out the scope of the effort needed to meet the goals. This should includes an implementation strategy identifying roles and interactions of governments and affected parties, a list of potential projects and their priorities, and commitments to funding. (3)

Response: An enhanced summary implementation strategy has been prepared for the final TMDL. The purpose of this strategy is to present the concepts and the vision on how the TMDL implementation is expected to take place. Development of specific detail of implementation will follow approval of the TNIDL and will likely be an ongoing effort over time.

Comment: The TMDL could use several different thematic maps to improve overall presentation. (3)

Response: *Development of thematic maps is beyond the scope of the TNIDL project. Although maps are useful visualization tools, they are not a required component of a TMDL. All of the information that would be shown on thematic maps can be found in other reference material. The information presented in the TMDL is geographically referenced in tables using the common location identifiers of land section and river miles. The final TMDL contains only a location map for showing the stream network in the Upper Chehalis River basin.

Comment: The TMDL should estimate the miles of streambank canopy that require active tree planting.

Response: The TMDL proposes the use of passive restoration to achieve the standards. The analysis shows that by allowing existing riparian vegetation to grow no active planting will be required to attain the TMDL goal. However, the planting of additional riparian vegetation where is does not currently exist will help speed up the time it takes to meet those goals. The detailed implementation strategy that must still be developed will identify programs and ways in which active planting can be accomplished to improve upon the passive restoration strategy.

Comment.- Design criteria on the width and structure of the riparian corridor is needed. (3)
Response. The model assumes that the late seral stage riparian corridor will achieve a density of 85%. This value represents the amount of solar radiation that is blocked by the canopy. If the riparian buffer width is too small, the actual density will be reduced and the TMDL goals will not be met. Additional investigation is needed to relate the density assumption used in the modeling to factors such as the width of the riparian buffer and structure measures such as basal area.
Comment. The analysis in the proposed TMDL fails to address many important landscape processes. (4)

Response. It would not be possible to assess the effect of all landscape processes on the modeling results. The two most important manageable factors, instrearn flow and channel morphology were assessed. In addition, a technical discussion of many landscape processes on stream systems has been added to the final TNML as an appendix.

Comment. No analyses were done to document the uncertainty in model predictions. (4)

Response: The evaluation of the model performance was conducted in the proposed TMDL through calibration and validation. Several different statistical metrics were used to assess the bias, precision, and accuracy of the model. In the final TMDL, information from a sensitivity analysis conducted by a Timber. Fish, and Wildlife study was added to show the most influential model parameters. The TMDL did not use a newly developed model framework for which the model construct and numerical representation of processes need to be verified. We do not feel that model confirmation is needed since SNTENT has been successfully and widely used in numerous other projects.

Appendix E

Processes Influencing Stream Systems

PATHWAYS OF HUMAN 1NFLUENCE ON WATER TEMPERATURE IN STREAM CHANNELS

(Prepublication Draft: June 1999)[‡]

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ABSTRACT

In-channel water temperature, the most common water quality metric used to measure the amount of heat in a stream, is a function of the amount of heat energy delivered to the stream channel and the amount of water flowing in the channel. Over the last 20 years, advances in the field of river ecology have lead to an understanding of streams as integrated systems comprised of at least three components: channel, riparian zone/floodplain, and alluvial aquifer. External factors ("drivers") determine the net amount of heat energy and water delivered to the integrated stream system, but the internal structure of the stream components determines how heat and water are distributed and exchanged amongst or lost from the system components. Therefore, channel water temperature is ultimately determined by the interaction between external drivers of stream temperature and the internal structure of the integrated stream system. This paper provides a synoptic discussion of the external drivers of stream temperature, the internal hydrologic processes that insulate and buffer channel water-temperatures, and the mechanisms of human influence on drivers and stream structure, which ultimate alter the temperature regime of stream networks. Key conclusions include: 1) management of in-channel water flow is a critical element for re-establishing desirable thermal regimes in streams; 2) in addition to modified riparian vegetation structure, human alteration of groundwater dynamics and channel morphology are critical pathways of human influence on channel-water temperature; and 3) watershed assessment, including analyses of land-use history and analysis of historic vs. contemporary structure of the stream channel, riparian zone, and alluvial aquifer, is an important tool in developing effective management prescriptions for meeting water quality targets for in- channel temperature. Although the discussion and examples in this paper have a Pacific Norwest focus, the ecological principles and processes discussed are applicable to lotic systems in general.

INTRODUCTION

Current understanding of stream ecology indicates that streams are comprised of at least three integrated and interdependent components: the channel, riparian zone, and alluvial aquifer (Findlay 1995; Gibert et al. 1994; Stanford and Ward 1988, 1993; Ward 1989, 1998a, 1998b; Ward and Stanford 1995). From this perspective, the "edge" of a river is not defined by its

[‡] Preferred citation: Poole, G.C. In preparation. Pathways of human influence on water temperature in stream channels. U.S. Environmental Protection Agency, Region 10. Seattle, WA.

channel margin, but rather by the edge of the riparian zone (Gregory et al. 1991). Similarly, the "bottom" of a river is not the stream bed, but the bottom of the alluvial aquifer (Ward et al. 1998). These components are set within the context of the phreatic surface and groundwater flow network in the catchment. (Figure 1).

The **stream channel** is the area where water flows across the land surface. The channel boundary is approximately the typical annual high water level on each stream bank. Some streams have multiple channels (Kellerhalls et al. 1976; Leopold and Wolman 1957; Mosley 1987). This underscores the fact that a steam channel may be discontinuous in cross section, comprised of the main channel, side channels, and perhaps channels that are active only during the period of annual high flow. Where floodplains are present, the locations of channels change over time (Leopold et al. 1964; Naiman et al. 1992). Sometimes these changes occur gradually over decades as streams erode the outer banks along stream meanders and deposit sediment

along the inner banks. In other instances, streams in flood stage rapidly cut new channels or re- capture previously abandoned channels (Nanson and Knighton 1996). Channel migration processes are important for the creation and maintenance of floodplain complexity. This complexity, in turn, drives important in-stream dynamics (e.g., nutrient and carbon cycles, natural floodwater storage, and buffering water temperature) and enhances the variety of available aquatic and terrestrial habitats thereby supporting biological diversity (Abbe and Montgomery 1996; Creuze des Chatelliers et al. 1994; Harvey and Bencala 1993; Sedell and Froggatt 1984).

The **riparian zone** is the area of land influenced by moisture derived directly from the stream. For small streams, this area may only extend a short distance (100 to 10 1 in) laterally from the 103 channel margin. However, for larger streams, the riparian zone extends much further (101 to m), at least to the edge of the active floodplain (Gregory et al. 1991). For the great rivers of the world such as the Mississippi and Amazon, the riparian zone sometimes extends even further (103 to 105 in) (Salo et al. 1986). Riparian zones form the transition zone (or *ecotone*) between terrestrial and aquatic systems. Periodic flooding of the riparian zone encourages the exchange of water, nutrients, sediments, and energy between the river channel and the riparian zone. This exchanges creates unique habitats, enhances natural productivity, and drives biological process that contribute to the ecological complexity and integrity of stream systems (Ward 1998b).

The sediments that have been deposited and sorted as the result of hydraulic processes (alluvium) along with the groundwater contained therein form the alluvial aquifer (Creuz6 des Chatelliers et al: 1994). Generally speaking, the alluvial aquifer includes the sediments that underlie the riparian zone (including the floodplain) and the sediments that comprise the streambed. In streams that flow across bedrock, alluvial deposits (and therefore the alluvial aquifer) may be no more extensive than pockets of sediment trapped in depressions in the bedrock. However, in most large rivers, the entire floodplain is built from alluvial deposits often many meters thick. Stream channels actively exchange water back and forth with their alluvial aquifer (Gibert et al. 1994). *Hyporheic groundwater* is water that infiltrates into the alluvial aquifer from the stream, travels along localized subsurface flow pathways for relatively short periods of time (perhaps from 10-2 to 104 days), and re-emerges into the stream channel downstream without leaving the alluvial aquifer. The portion of the alluvial aquifer that contains at least some hyporheic groundwater (White 1993) is referred to as the *hyporheic zone* (Brunke and Gonser 1997;

Stanford and Ward 1988). Therefore, there are two types of groundwater that influence streams, hyporheic groundwater and *phreatic groundwater* (water derived from the catchment aquifer). Phreatic groundwater often enters the hyporheic zone and mixes with hyporheic groundwater; therefore, the groundwater ultimately released into the stream channel at a given point may be predominantly phreatic, predominantly hyporheic, or a mixture of both. The hyporheic zone can exert an extremely strong influence on the biological, chemical, and physical processes that occur in a river (Brunke and Gonser 1997; Findlay 1995; Stanford and Ward 1993).

WATER TEMPERATURE IN STREAM CHANNELS

Water temperature is not a simple measure of the *amount* of heat energy in a stream reach. Temperature is proportional to heat energy divided by the volume of water:

$$\text{Water Temperature} \propto \text{Heat Energy / Water Volume}$$

Therefore, conceptually, water temperature can be thought of as a measure of the "concentration" of heat energy in a stream. All water contains heat energy; warmer water simply contains a higher "concentration" of heat energy than does cooler water.

The heat load is a measure of the net amount of heat added to a stream channel; any increase or reduction in heat load will affect stream temperature by altering the amount of heat energy in the system. Theflow rate is a measure of the volume of water flowing in a stream channel. Substituting "heat load" and "flow rate" into the above equation results in:

$$\text{Water Temperature} \propto \text{Heat Load / Flow Rate}$$

Therefore, stream temperature is dependent on both heat load and stream flow; any processes that influences heat load to the channel or stream flow in the channel will influence the temperature of water in the stream channel and can be considered a driver of stream temperature. Since all water contains heat energy, heat energy is added to a stream channel any time water is added to the channel and lost any time water is removed. When cool water is added to a warm stream, the temperature falls not because heat energy was lost, but because the "concentration" of heat energy in the stream was diluted. In spite of the fact that heat energy is lost from a stream when water is removed from a stream, the temperature remains unchanged because the "concentration" of heat energy in the stream remains the same.[1]

Heat energy is also gained or lost by a stream without adding or removing water. Heat energy flows between the stream and atmosphere in a variety of ways that does not require the exchange of water (Naiman et al. 1992). Heat energy is transferred directly from the sun to the stream surface via the process of radiation. Heat in the atmosphere is transported to the stream surface via convection, conduction, and advection and is then transferred into the stream via conduction. When heat is added to or removed from a stream channel without altering flow, only the heat load is altered. Increasing the heat load while holding flow constant will increase stream

[1]Evaporation is an exception to this rule. The cooling effect of evaporation results from the fact that the water adsorbs additional heat energy as it changes state from a liquid to a vapor. This additional energy that is removed from the stream alters the ratio of heat energy to water volume in the stream.

temperature while decreasing the heat load will decrease stream temperature. By extension, then, it follows that the same heat load applied to a lesser flow will result in higher water temperatures in the stream channel. This illustrates that the flow rate in a stream channel is an important determinant of the stream's ability to resist temperature changes in response to a given heat load.

DRIVERs OF STREAM TEMPERATURE

Drivers of stream temperature generally operate beyond the boundaries of the stream and help to form the physical setting or context within which the stream flows. Drivers control the rate at which heat and water are delivered to the stream system and therefore have ability to actually cool or warm the water in the stream. Examples of stream drivers are listed in Table 1.

Atmospheric drivers interact with the geographic drivers (e.g., topography, lithology, and upland vegetation) in the basin to determine the rate and means by which water enters the stream. Ultimately, all stream flow derives from precipitation, but precipitation enters the stream via a number of pathways: directly, via surface flow, or via groundwater discharge after infiltrating the catchment aquifer.

Although some streams in and climates flow only as the result of surface run-off, most streams derive at least some of their flow from groundwater. Therefore the temperature of the surrounding upland aquifer is generally the "baseline" temperature from which stream temperature deviates. Channel water temperature trends away from groundwater temperature and toward atmospheric temperatures in a downstream direction.

As soon as groundwater enters the stream channel and is exposed to the atmosphere, heat exchange begins and the water begins to equilibrate with atmospheric temperature. In the absence of insulating, and buffering influences, streams will rapidly trend away from groundwater temperature and toward atmospheric temperature. Even in the presence of insulating and buffering influences, streams often naturally reflect a very gradual downstream trend in temperature. Groundwater from the catchment aquifer influences channel water temperature when it enters the stream channel; if the water in the channel has warmed or cooled while flowing downstream, lateral groundwater inputs moderate channel water temperature toward groundwater temperature.

Temperature of lateral surface water inputs to the stream network reflect the seasonal climate and is much less consistent over the year than that of groundwater inputs. Like groundwater inputs, however, lateral inputs from tributaries and surface run-off affect water temperature by pulling the channel temperature toward the temperature of the tributary/run-off.

PHYSICAL STRUCTURE OF STREAMS

Unlike drivers of stream temperature which operate outside the boundaries of the stream, the physical structure of a stream (as represented by channel and floodplain morphology, riparian vegetation structure, and the stratigraphy of the alluvial aquifer) exerts internal control of stream temperature. Rather than warm or cool a stream as the drivers do, the physical structures of a stream determines how well a stream resists warming or cooling. Stream structure is strongly influenced by the physical dynamics occurring within the stream (Beschta and Platts 1986; D'Angelo et al. 1997; Hawkins et al. 1997; Vannote et al. 1980). Unlike drivers, which deliver heat and water to the stream, the physical structure of a stream determines how well the water in a stream channel resists warming or cooling by determining the means and rates of heat and water entry into, flow through, storage within, and release from the stream system and its components.

A wide variety of stream characteristics affect the way water temperature in stream channels responds to natural drivers of stream temperature (Table 2). Some stream characteristics enhance processes that insulate streams by reducing the rate of heat or water flux into or out of the channel. Other physical characteristics of stream influence processes that buffer stream channel temperature by removing heat/water from the channel when temperatures/flows are high and releasing heat/water to the channel when temperatures/flows are low.

Insulating processes

Stream characteristics that influence the rate of heat exchange with the atmosphere can be said to insulate the stream. These characteristics include the height, density, and proximity to the channel of riparian vegetation and the width of the stream channel. Riparian vegetation shades the stream, blocking solar radiation from reaching the channel and reducing the heat load to the stream (Davies and Nelson 1994; Hostetler 1991; Li et al. 1994; Naiman et al. 1992). Vegetation also reduces wind speed across the stream channel. This action trapps air against the water surface thereby reducing conductive heat exchange with the atmospheric by decreasing the amount of heat energy delivered to the water surface via convection and advection (Naiman et al. 1992). Width influences channel surface area across which heat is exchanged; a greater surface area allows for more rapid conductive heat transfer. Under the same climatic conditions, narrower, deeper channels will-not exchange heat with the atmosphere as rapidly as shallow, wide channels. Similarly, riparian vegetation of a given height will shade a larger percentage of a narrow channel than a wide channel.

Buffering processes

Buffering processes may either heat or cool the stream channel at any given point in time, but buffers differ from drivers in several important ways. First, buffers operate by storing heat that is already in the stream system rather than by adding or removing heat from the stream. For instance, buffers may transfer water and heat between the components of the stream (i.e., from the alluvial aquifer to the stream channel), but water and heat are not added to nor withdrawn from the system. Secondly, buffers operate by integrating variation in flow and temperature over time. If water and heat flux into the stream were constant, buffers would have no effect on channel water temperature.

The two-way exchange of water between the alluvial aquifer and stream channel (hyporheic flow) is an important stream temperature buffer. The magnitude of hyporheic flow in a stream in determined by the stream channel pattern, the structure of the alluvial aquifer, and the variability in the stream hydrograph (Creuz6 des Chatelliers et al. 1994; Evans et al. 1995; Evans and Petts

1997; Hendricks and White 1995, Henry, 1994 #435; Morrice et al. 1997; White et al. 1987; Wondzell and Swanson 1996)

Hyporheic flow occurs at three different spatial and temporal scales. At the finest scale (streambed scale), hyporheic flow is driven by alternative pool/riffle sequences in the stream channel (Vaux 1968; White et al. 1987). Water enters the stream bed (i.e., the top of the alluvial aquifer) at the downstream end of pools, flows through the streambed sediments, and re-emerges into the channel in a riffle downstream (Figure 2). Channels with complex streambed topography have higher rates of streambed hyporheic flow (Harvey and Bencala 1993). Streams with relative little streambed complexity may lack the pool/riffle sequences that drive streambed hyporheic flow. Streambed scale hyporheic flow pathways apt to influence channel temperature might be anywhere from 10^{-2} to 10^{1} days in duration. At an intermediate spatial scale (meander- bend scale) hyporheic flow is driven by the development of mid-channel bars and meander bends in streams (Wroblicky et al. 1994) and by the presence of side channels, backwaters, and abandoned channels (Stanford et al. 1994). Water enters the upstream end of a gravel or sand bar, flows through the underlying alluvium, and re-emerges into the stream at the downstream end. Similarly, hyporheic water follows preferential flow pathways underneath abandoned channels or flood channels and re-emerges in backwaters and side channels or as springbrooks on the floodplain which eventually rejoin the river (Stanford and Ward 1992). Stream sinuosity and the presence of geomorphic features such as side channels, flood channels, and backwaters are critical influences on the magnitude of hyporheic flow at the meander-bend scale. Hyporheic flowpath duration at the meander-bend scale might be anywhere from 10^{0} to 10^{3} days in duration. At the coarsest scale (floodplain scale) water tends to enter the alluvial aquifer at the upstream end of floodplains, flow laterally through the alluvial aquifer, and re-emerge at the lower end of the floodplain (Stanford and Ward 1993). The simple model of a trough placed on a slight incline and filled with marbles provides an analogy. Water poured into the upper end of the trough will trickle down through the marbles, flow laterally along the trough through the marbles, and reemerge at the surface of the marbles before spilling over the lower end of the trough. Hyporheic flow duration at the floodplain scale may perhaps be on the order of 10^{2} to 10^{5} days.

Hyporheic flow at the streambed and meander-bend scales buffer channel water temperature because hyporheic flow pathways are short in duration and are often somewhat separate from the phreatic groundwater flow network. Because of the short residence time and discrete flow pathways, hyporheic water may not equilibrate with mean groundwater temperature before re- emerging into the stream. For instance, if a hyporheic flow pathways is four months in duration, the temperature of emerging hyporheic water may be very close to the channel temperature from four months ago (C. Frissell, University of Montana, unpublished data). Since river temperature fluctuates in diel cycles, the most significant buffering affect of streambed scale hyporheic flow occurs when water from the alluvial aquifer re-enters the channel at a time of day opposite that of it's entry into the aquifer. Similarly, meander-bend scale hyporheic flow will be most effective as a temperature buffer if water infiltrates and re-emerges at opposite times of the year. Thus, hyporheic exchange results in a horizontal and vertical mosaic of groundwater temperature across the alluvial aquifer, the pattern of which is determined by the structure of the alluvial aquifer, the morphology of stream channel, and variations in channel flow and temperature (Evans et al. 1995; Evans and Petts 1997; Stanford et al. 1994; White et al. 1987). Because of intra- and inter-day variations in stream temperature, streambed and meander-bend flow pathways of virtually any duration have the potential to buffer stream temperature.

The flow path duration of floodplain scale hyporheic flow is likely long enough to allow temperature to equilibrate with the mean subsurface temperature. Therefore, floodplain scale hyporheic flow likely buffers stream water temperature by extracting water of varying temperature from the channel and returning that water to the channel at a relatively constant temperature approximating mean annual air temperature.

The hydrograph of the stream also plays an important role in driving hyporheic exchange of water. Although hyporheic exchange (both recharge and discharge of the alluvial aquifer) occurs year-round, the net recharge to the alluvial aquifer varies seasonally depending on the flow regime in the channel (Creuz6 des Chatelliers et al. 1994; Hendricks and White 1995; Morrice et al. 1.997; Wroblicky et al. 1998). Positive net recharge generally occurs during high-flow periods; negative net recharge occurs during periods of low flow. In streams where flood spates occur during winter and spring months, the highest aquifer recharge period occurs while the stream channel is coldest. In these systems, hyporheic exchange and floodplain storage of floodwaters may be an especially effective buffer against stream channel warming because the aquifer is recharged predominantly with cold water and this cold water is discharged predominantly during baseflow periods when the highest stream temperatures are apt to occur.

VARIATION IN STREAM STRUCTURE

Over time, humans have substantively altered the structure of stream systems and the physical context through which streams flow. It is sometimes difficult to imagine the historic structure of streams based on an examination of their current state. A conceptual understanding of the processes and structures that influence stream temperature in unaltered systems can provide a framework from which to understand the breadth of human activities that may substantively influence stream temperature. The following discussion attempts to provide a brief synopsis of stream and catchment dynamics that influence stream temperature and a discussion of how those dynamics are influenced by the natural diversity in stream system structure.

The physical structure of stream channels, riparian zones, and alluvial aquifer changes along the continuum from headwaters to river mouth (Creuz6 des Chatelliers et al. 1994; Vannote et al. 1980). For a summary of the ecological implications for these structural changes from low-order (headwater streams) to mid-order to high-order (mainstem rivers) streams, see Naiman et al. (1992). As the structure of streams changes from headwaters to mouth, the processes that drive and mediate stream temperature vary in their relative importance. Generally speaking, as streams become larger, insulating processes become less effective and buffering processes, which are driven by stream morphology, become more important.

Low-order Streams

While notable exceptions exist (e.g. alpine meadow streams), headwater streams, as a rule, have smaller, steeper, narrower channels and narrower riparian areas. These small channels generally carry small amounts of water and therefore, in the absence of processes that cool, insulate, or buffer the stream, experience wide temperature swings as they exchange even relatively small amounts of heat with the atmosphere. Substrate particle sizes in the alluvial aquifer of low-order streams are generally coarse suggesting that there is little resistance to the flux of water between the stream bed and stream channel, subsurface flow rates are high (D'Angelo et al. 1993) and subsurface residence times are short. However, the alluvial aquifer may be poorly developed. Limited aquifer size combined with the low porosity of coarse alluvium results in limited potential for water storage in the alluvial aquifer.

Small channels, on the other hand, are easily shaded by topography and riparian vegetation, which provides substantial resistance to the exchange of heat with the atmosphere. Except during snowmelt periods and heavy precipitation events, small streams derive a large percentage of their water from lateral groundwater inputs, which can provide substantial thermal stability during periods of low flow.

Since most headwater streams generally lack significant alluvial aquifers, hyporheic flow occurs predominantly at the streambed scale. In forested streams, individual pieces of large woody debris (L)WD) lodge in the channel and trap sediments that would otherwise be washed downstream (Beschta and Platts 1986; Montgomery and Buffington 1993; Nakamura and Swanson 1993). LWD also creates turbulent flow that contributes substantially to variation in streambed topography - a critical driver of streambed-scale hyporheic flow. Therefore, large wood may play an important, albeit indirect role in buffering small streams against temperature changes by trapping sediments and increasing the storage capacity of the alluvial aquifer and by contributing to streambed complexity that drives streambed-scale hyporheic flow.

Mid-order Streams

Moderate gradients and somewhat wider channels characterize mid order streams. Morphology often alternates between reaches closely confined in their valleys and unconfined reaches that occupy montane flood plains. Substrate particle size is medium to coarse, allowing for substantive hyporheic exchange within and across the streambed, though streambed resistance may be higher than in low-order streams (D'Angelo et al. 1993). Alluvial aquifers can be somewhat to very well developed in floodplain reaches. The high porosity of sand/gravel alluvium allows for substantive water storage and transport in these alluvial aquifers, but, relative to headwater streams, finer grained sediments suggest slower (though still rapid) subsurface flow rates and short to moderate residence times.

Because mid-order channels carry more water, their capacity to absorb heat without substantive changes in temperature is higher than low-order streams, but the somewhat wider channels are less easily shaded by riparian vegetation and have more surface area to exchange heat with the atmosphere. In floodplain reaches, riparian vegetation likely becomes a less effective insulator as the channel widens, the littoral zone widens pushing vegetation away from the low-flow water surface, and topographic shading is reduced as the sides of the valley retreat from the stream. Still, in confined reaches where channels are narrower, riparian vegetation and topographic shade may be important insulators against heat exchange with the atmosphere while hyporheic buffering capacity is likely reduced. Flow from small tributaries is often the predominant source of lateral water inflow; therefore, the riparian condition of tributaries may play a major role in determine channel temperature in mid-order streams.

Channel pattern and morphology begins to play a key role in buffering channel water temperature on montane floodplains. Sinuosity and the presence or absence of gravel-bars, backwaters, and multiple channels determines the potential for hyporheic flow at the meander- bend scale (Stanford and Ward 1993). Multiple channels also allow for more effective riparian shade (Sedell and Froggatt 1984) since the width of each channel is less than the width of a single channel would be.

Large wood continues to play an important role in determining stream morphology. Aggregates of large wood act as roughness elements that redirect flow, causing evulsions and creating pools, bars, and side channels (Abbe and Montgomery 1996; Nanson and Knighton 1996). Single pieces of large wood are often mobile and therefore might not store sediments from year to year. However, hydraulic forces in the proximity of large wood continue to contribute to streambed complexity and streambed-scale hyporheic flow.

High-order Streams

Low gradients and wide channels are typical of high-order streams. Although most are single channels today, many high order streams once had complex assemblages of active and seasonally active channels, meander-bends, and oxbow lakes (Sedell and Froggatt 1984). Substrate particle size is typically fine to very fine, reducing the rate of flux into the streambed and alluvial aquifer. Alluvial aquifers are large and well to extremely well developed; combined with the moderate porosity of the sediments, this results in a large potential for water storage in the alluvial aquifer. High-order channels move large amount of water and therefore can absorb and release relatively large amounts of heat energy without substantive temperature swings observed in smaller channels. Riparian vegetation and topography generally provide little to no insulation for a wide, single channel with a well-developed littoral zone. The sheer volume of water delivered from upstream may overwhelm temperature effects of lateral inflow from phreatic groundwater sources and tributaries.

The catchment aquifer may influence channel water temperature as much by removing water from the alluvial aquifer as by supplying water to it. Where alluvial aquifers of high-order streams lose water to the catchment aquifer, hyporheic exchange is reduced since water entering the alluvial aquifer from the stream channel is apt to be drawn out of the bottom of the alluvial aquifer rather than returning to the stream channel. This has the effect of both reducing the amount of water in the stream channel as well as damping an important temperature buffer within the stream system.

Meander-bend and floodplain scale hyporheic flow likely provides buffering against temperature changes in the stream and result from stream's channel pattern and morphology. Meander- bends, side channels and other features such as oxbow lakes enhance floodplain scale hyporheic flow. Variable hydrographs likely play an important roll in alluvial aquifer discharge and recharge. The fine-grained substrate has higher resistance to groundwater flow thereby increasing the duration of hyporheic flow paths resulting in discharges from the hyporheic zone being a more constant temperature over the course of the year. Substantial networks of side-channels and mid-channel bar formation allow for the inter-fingering of channels with riparian vegetation, providing a much greater opportunity for channel interactions with the riparian zone (Sedell and Froggatt 1984) including channel shading. In short, the complexity of channel patterns across the floodplain creates a diversity of surface and subsurface flow pathways within which water to moves downstream. These differential flow rates, when combined with seasonal variation in temperature and river stage, allow for stratification, storage, insulation, and remixing of waters with different temperature within and across the floodplain. The resulting mosaic of water temperatures across the floodplain surface and within the floodplain sediments ultimately buffer the main channel against temperature change so long as the natural connections between the floodplain and the stream channel are operational (Ward and Stanford 1995).

PATHWAYS OF HUMAN INFLUENCE ON RIVER TEMPERATURE

Based on an ecological understanding of the role of drivers, physical characteristics of stream systems, and resulting insulating and buffering processes in influencing channel temperature, several key conclusions can be drawn:

1) Human activities that alter the ecological drivers of stream temperature can affect water temperature in stream channels by changing: a) the amount of heat energy delivered to the channel (heat load); or b) the regime of water flow in the channel.
2) In stream systems with different structural characteristics (e.g., low-, mid-, and high- order streams), the dominant mechanism that controls water temperature will be different. Therefore, streams with different structural characteristics will differ in their sensitivity to specific human activities that alter ecological drivers and/or stream system structure.
3) The physical structure of streams influences how the water temperature in a stream channel will respond to a given heat load and flow regime. Changing the physical structure of a stream system has the potential to influence both the heat load to the channel and the streams ability to withstand a given heat load without substantive increase in channel water temperature (i.e., the stream's "assimilative capacity" for heat).

Dams, water withdrawals, channel engineering, and the alteration of vegetation (upland or riparian) alter the drivers of stream temperature, the structure of stream systems, or both. Therefore, they are all potential mechanisms by which human activities can influence stream temperature. Table 3 summarizes these impacts by operative mechanism; Figure 3 diagrams the pathways of influence that would tend to increase temperature during low flow periods.

Dams - Darns directly effect downstream temperature based on the mechanism of water release (top- or bottom-release). When considering stream temperature alone, dams can be operated to provide "desirable" stream temperature regimes directly downstream (e.g. through selective withdrawal of water from varying depths in the reservoir) (Stanford and Hauer 1992). However, from a broader perspective, other ecologically deleterious impacts from flow regulation (Ward and Stanford 1995) including effects on temperature insulating and buffering processes are not so easily addressed.

Commonly, dams store spring and summer flows for use in irrigation, recreation, and in order to generate hydropower during cold winter months. In basins where water rights are overallocated, there is a tendency for dams to be operated such that summertime flows below darns are severely restricted. This massive reduction in flow (sometimes to the point of river stagnation) affects water temperature by reducing or virtually eliminating the assimilative capacity of the stream for heat.

Flow regulation also reduces the magnitude of hyporheic flow. As a temperature buffer (vs. an insulator or driver), hyporheic flow relies on the differential storage of heat and water over time as a means of moderating stream temperature. Differential heat and water storage is driven by variation in stream temperature and flow. Since flow regulation dampens variation in both flow and temperature, the potential for hyporheic exchange to act as a temperature buffer is reduced by flow regulation (Ward and Stanford 1995). Dams also affect hyporheic flow by altering the downstream morphology of the channel and geornorphology of the alluvial aquifer. The downstream flux of sediment along the river continuum is disrupted which can resulting in downcutting, bed armoring, and, when combined with reduced peak flows, channel stabilization. (Church 1995; Simons 1979). The lack of channel. migration and evulsion disrupt fluvial processes critical to creating and maintaining heterogeneous channel patterns (Stanford et al. 1996; Ward and Stanford 1995) and alluvial aquifer structure (Creuz6 des Chatelliers et al. 1994) that drive hyporheic flow at the streambed and meander-bend scales.

Dams are often built at constrictions in rivers just below large alluvial floodplains in order to maximize the storage capacity of the dam while minimizing the size of the structure. Therefore, dams tend to inundate free-flowing alluvial river segments where hyporheic buffering and groundwater inputs are most prevalent thereby reducing the assimilative capacity for heat in the stream. For example, dams have inundated all free-flowing alluvial segment on the mainstern Columbia River with the exception of the Hanford Reach (National Research Council 1996).

Water Withdrawals

Withdrawals from streams have the effect of reducing flow and therefore the assimilative

capacity of the streams for heat (Dauble 1994). Although some of this water is eventually returned to the stream, this fraction is typically low; Solley et al. (1993) estimated that only approximately one-third of the water withdrawn in the Pacific Northwest was returned to lakes and streams (as cited in (National Research Council 1996)). Also, in many cases, water returned to the river after withdrawal is at a markedly different temperature than it was when withdrawn, thereby affecting the heat load to the stream. The water withdrawals are typically used for industry, municipal water supplies, or agricultural. Regulations may require that the temperature of industrial and municipal returns be restored before they are discharging to the stream, but the fate of water withdrawn for agriculture is less certain. Water from agricultural withdrawals that is not transpired or evaporated will eventually return to the stream. In some cases, this water percolates into the phreatic flow network after application and returns to the stream as groundwater. Although there is the theoretical.potential to moderate stream temperature by using irrigation to increase phreatic groundwater inputs to the stream, the impact on the stream of the initial reduction in stream flow is not likely to be overcome by returning a small fraction of that water through phreatic flow pathways. Further, recharging aquifers by allowing water to percolate through agricultural fields carries the risk of groundwater contamination by pesticides
and fertilizers.

Drain tiles are commonly installed in agricultural fields to remove excess water from the soil after irrigation. Water flowing out of these drain tiles usually enters a network of artificial ditches, which deliver the water back to the stream. The temperature of these returns can be more extreme than the stream temperature, further exacerbating the temperature affects of agricultural withdrawals (Dauble 1994; National Research Council 1996).

Major withdrawals from wells penetrating the phreatic groundwater network that feeds a stream can reduce flows in a stream channel (Bouwer and Maddock 1997; Glennon 1995; Wilber et al. 1996). However, when considering the hyporheic zone as a source of stream temperature buffering, a substantial influence on water temperature may precede marked reductions in in- channel flows. Less noticeable than reductions in channel flow are subtle changes in the net exchange of water between the hyporheic zone and larger phreatic groundwater system and in groundwater flow within the alluvial aquifer (Long and Nestler 1996). Withdrawals via wells can result in the loss of hyporheic water to the larger phreatic groundwater system (Hibbs and Sharp 1992). In such a case, the buffering capacity of the hyporheic flow network could be substantially reduced because hyporheic water would not be returned to the stream channel to moderate channel-water temperature.

Channel engineering

Straightening, diking, dredging, snagging (removal of LWD), and rip-rapping of channels are all undertaken in an effort to prevent lateral movement of stream channels and to allow stream channels to move water more efficiently. These activities focus the erosive energy of streams toward the middle of the channel, encouraging downcutting (National Research Council 1996), and ultimately decreasing the interaction of stream channels with their floodplain in all but extreme flood events. This loss of ecological connectivity between the channel and floodplain can occur through one or all of the following mechanism. First, because engineered channels carry water more efficiently, both the amount of time floodwaters spend on the floodplain and the surface area inundated is reduced during average annual high-flow events. This reduces the opportunity for floodwaters to penetrate the alluvial aquifer (Steiger et al. 1998) and therefore reduce baseflow in the river by reducing groundwater discharge during the low-flow season. Second, engineered channels typically lack heterogeneity in channel pattern and streambed topography (Jurajda 1995), thereby reducing hyporheic flow. Third, removal of LWD from the channel eliminates major structural elements responsible for creating channel pattern heterogeneity (Abbe and Montgomery 1996; Piegay and Gurnell 1997; Sedell and Froggatt 1984). Fourth, when downcutting occurs, the stream bed is lowered; stream water no longer reaches the floodplain surface and existing subsurface preferential flow pathways can be disconnected from the stream channel (Wyzga 1993). In a manner similar to flow regulation below dams, channel modification severs linkages between channel and floodplain and reduces groundwater buffering of stream flow and temperature (Ward 1998a) and eliminating interactions between the channel and riparian zone that would insulate the stream from exchange of heat with the atmosphere.

Upland vegetation

Whether the catchment of a stream is urban, forested, rangeland, or agriculture, disturbance of upland vegetation associated with human activities has the tendency to increase sediment delivery, warm lateral water inputs, alter the relative amount of surface runoff (and therefore, peak flows), and alter upland water infiltration and groundwater recharge. (Naiman 1992; National Research Council 1996). Increasing sediment load can also clog coarse streambed gravels with fine sediments (Megahan et al. 1992) decreasing streambed conductivity and reducing the exchange Of groundwater and surface water across the streambed (Schalchli 1992). Where shallow groundwater systems vegetation in the catchment can alter are important sources of stream water, removal of vegetation in the catchment can alter upland groundwater temperatures, increasing the temperature of water delivered to the stream (Hewlett and Fortson 1982). Depending on basin characteristics and the nature of the land use, upland land-use can also augment (Harr et al. 1982; Ziemer and Keppeler 1990) or reduce (Burt and Swank 1992; Harr 1980) baseflows thereby altering the assimilative capacity of the stream. When considering stream channel temperature, the most pervasive and best studied effect of upland land use is arguably the change in channel morphology (usually widening and shallowing of channels) in response to increased sediment load (Dose and Roper 1994; Knapp and Matthews 1996; Richards et al. 1996; Sidle and Sharma 1996). Wider channels have more surface area and are not as easily shaded, thereby facilitating the exchange of heat with the atmosphere.

Riparian Vegetation

Removal or alteration of riparian vegetation can have important implications for stream temperature (Beschta and Taylor 1988; Hostetler 1991; Naiman 1992; National Research Council 1996). The primary mechanism of thermal control of riparian vegetation is through shading the stream and trapping air next to the stream surface. However, removal of riparian vegetation can also destabilize streambanks, facilitating erosion and increasing sediment loads. Increased sediment and unstable banks can cause changes in streambed and channel morphology (Li et al. 1994) that alter the rate of heat exchange with the atmosphere and restrict hyporheic flow by reducing streambed permeability. Riparian vegetation is also a primary source of LWD to the channel. Clearly denudation of riparian vegetation can have major consequences for in- channel processes. However, since the size of LWD (Hauer et al. In press; Ralph et al. 1994) and rate of delivery can be critical to determining its influence on the channel, even the selective removal of standing riparian vegetation may have important ramifications for channel morphology (and therefore channel temperature) over time.

MANAGEMENT OF CHANNEL WATER TEMPERATuRE

A holistic understanding of the pathways of human influence on water temperature in stream channels underscores the need for an integrated approach to managing and restoring channel water temperature. To be effective, management programs designed to prevent degradation of water temperature or restore previously degraded systems should consider the breadth of practices occurring in the basin in order to determine which are apt to be the most influential on water temperature. Restoration of historic channel structures, channel-forming processes, sediment delivery, and flow regimes (Poff et al. 1997; Stanford et al. 1996) may be critical to the re-establishment of historic temperature regimes in large rivers.

Clearly not all of the pathways illustrated in Figure 3 are operational in any one catchment. Determining which human activities have been or may be most influential on water temperature is important for designing an effective management strategy. Watershed analysis is a powerful tool for determining the current and potential pathways of human influence on aquatic systems (Montgomery et al. 1995). The analysis should include an assessment of historic stream structures and processes, thereby providing a referent for assessing the present-day influences on stream temperature (Kondolf and Larson 1995). This analysis should attempt to document, in a spatially explicit manner, the historic channel morphology, riparian structure, and extent of the alluvial aquifer along the stream network. An assessment of management history and ongoing activities within the basin (Wissmar et al. 1994) is useful for interpreting identified changes in stream structure and for making strong inference regarding causal linkages between management activities and degradation of water temperature. Additionally, an analysis of the present day channel morphology, riparian structure, and extent of the alluvial aquifer along the stream network is helpful in prioritizing stream segments for restoration and in the design of effective management prescriptions. The phrase "effective prescriptions" means prescriptions that are specifically designed to protect or restore appropriate hydrologic processes based on an analysis of the historic stream structure throughout the stream network.

SUMMARY

Since stream temperature is a measure of the amount of heat energy per unit volume of water, changing either the amount of heat energy entering the stream or the amount of water flowing in the channel has the potential to alter stream temperature. Further, since a diversity of physical processes in the stream channel, riparian zone, and alluvial aquifer influence the temperature of water in stream systems, degradation of stream temperature can result from modification of external drivers as well as modification of the structure of the integrated stream system.

Although the discussions, examples, and literature cited in this paper were drawn primarily from the Pacific Northwest of the U.S.A, the principles, processes, and integrative approach outlined in this paper are applicable to and appropriate for lotic systems in general.

Depending on the structure of a stream system, different processes are primary determinants of in-channel water temperatures. In order to be effective, management prescriptions designed to restore or protect water temperature dynamics in stream systems must be matched to the dominant processes that influence (or historically influenced) channel-water temperatures in a given stream. For instance, restoration of riparian vegetation will likely not be sufficient to meet temperature standards in streams if channel morphology played an important historic role in mediating water temperature, but has been severely degraded. Recovery and protection of stream temperature dynamics might be best accomplished by identifying the dominant historic external drivers and internal structural modifiers of water temperature in a spatially explicit manner across a basin and designing spatially explicit management prescriptions to address relevant human influences.

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Table 1: Examples of natural drivers of channel water temperature

Topographic Shade	Solar angle
Upland Vegetation	Cloud cover
Precipitation	Relative humidity
Air temperature	Phreatic groundwater temperature & discharge
Wind speed	Tributary temperature & flow

Table 2: Stream structures that influence insulating and buffering characteristics.

Component Characteristic	*Ecological function:*	*Determined by:*
Channel		
Channel slope	-Influences flow rate.	catchment topography
Channel substrate	-Particle size determines resistance to groundwater flux -Influences channel roughness and therefore flow rate	flow regime, sediment sources, stream power
Channel width	-Determines surface area for convective heat exchange	flow regime, sediment sources, stream power, bank stability
Streambed topography	-Determines gradients that drive hyporheic flux	flow regime, sediment sources, stream power, bank stability, large roughness elements (e.g., large woody debris)
Channel pattern	-Determines gradients that drive hyporheic flux -Determines potential shade from riparian vegetation	flow regime, sediment sources, stream power, bank stability, large roughness elements, valley shape
Riparian Zone		
Riparian Vegetation	-Provides shade to reduce solar radiation -Reduces wind-speed to reduce advective heat transfer -Traps air against the stream to reduce conductive heat transfer -Provides bank stability	Vegetation height, density, growth form, rooting pattern
Riparian zone width	-Influences potential for hyporheic flux	(same as channel pattern)
Alluvial Aquifer		
Sediment particle size	Influences potential for hyporheic flux	(same as channel substrate)
Sediment particle sorting	-Influences diversity of subsurface temperature patterns by determining stratigraphy -Influences extent of hyporheic flux	(same as channel substrate)
Aquifer depth flux	-Influences extent of hyporheic	(same as channel pattern)

Table 3. Mechanism and influences of pathways of human influence on channel water temperature.

Process / Implication	**Influence and Mechanism**
Reduced phreatic groundwater discharge results in reduced assimilative capacity	Removal of *upland vegetation* decreases infiltration of. groundwater on hillslopes and reduces baseflow in streams. Pumping *wells* for irrigation or municipal water sources can reduce baseflow in nearby streams and rivers.
Reduced stream and tributary flow during low-flow periods reduces assimilative capacity	*Water withdrawals* reduce baseflow in streams and tributaries and draw down the water table in the alluvial aquifer. *Dams* alter the flow regime of a river. Removal of upland vegetation result in flashier stream flow *Dikes and levies* confine flows that would otherwise interact with the floodplain and recharge the alluvial aquifer.
Simplified alluvial system structure reduces assimilative capacity by reducing hyporheic flow.	*Dams* reduce peak flows that rejuvenate the alluvial aquifer structure. Removal of *upland vegetation* increases fine sediment load, which clogs gravels and reduces hyporheic exchange. *Dikes and levies* confine flood-flows that would otherwise interact with the floodplain and rejuvenate alluvial aquifer structure; channelization severs natural subsurface preferential flow pathways. *Riparian management* may remove large woody debris (and its sources) that contributes to streambed complexity.
Simplified channel morphology reduces hyporheic flow reducing assimilative capacity; wider, consolidated channels are less easily shaded and have greater surface area increasing heat load	Removal of *upland vegetation* increases peak stream power and/or increases sediment volumes altering the interaction between water and sediment regimes and changing channel morphology. *Dams* remove peak flows that maintain channel morphology *Dikes and levies* confine flood flows that maintain channel morphology and decrease subsurface floodwater storage and, therefore, reduce groundwater discharge during baseflow periods. *Riparian management* may remove large woody debris (and its sources) that contributed to streambed complexity.
Reduced riparian vegetation reduces shade and increases heat load.	Riparian management may reduce shade to the channel and reduce the amount of air trapped by the vegetation, increasing convective and advective heat transfer from the atmosphere to the riparian zone and stream surface.

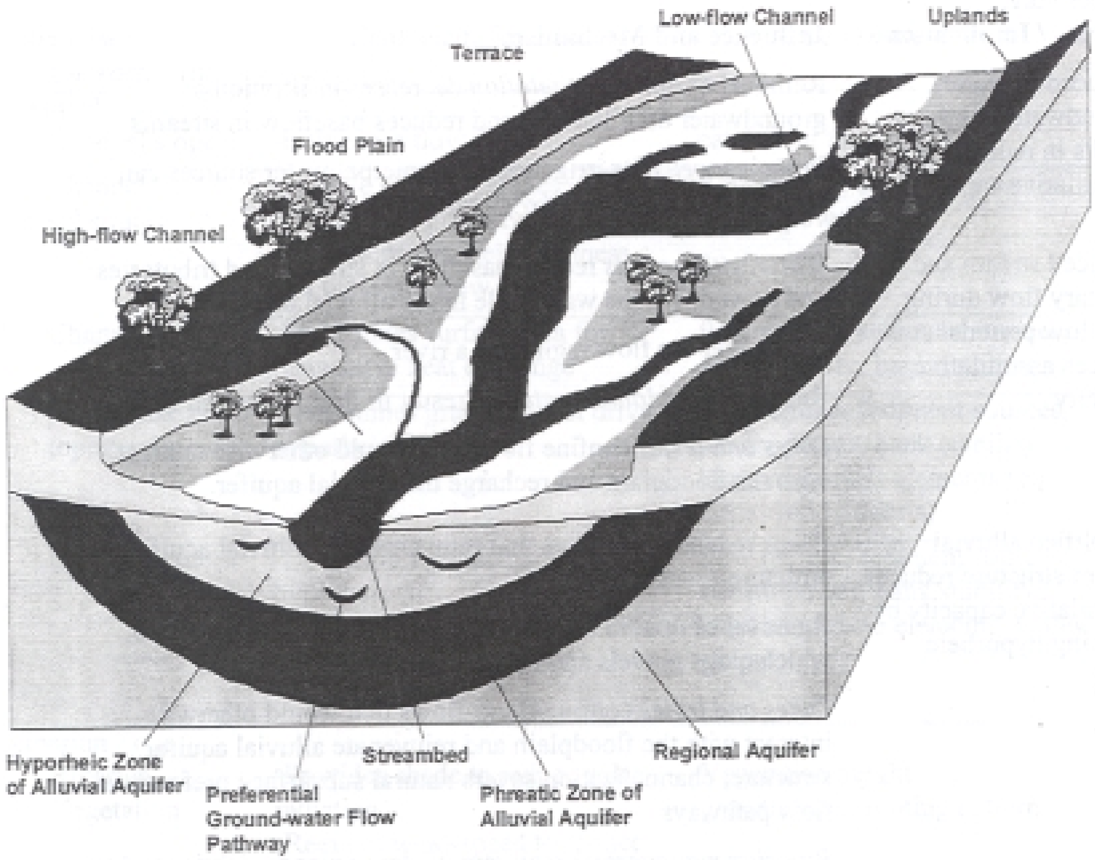


Figure 1. Elements of a stream system.

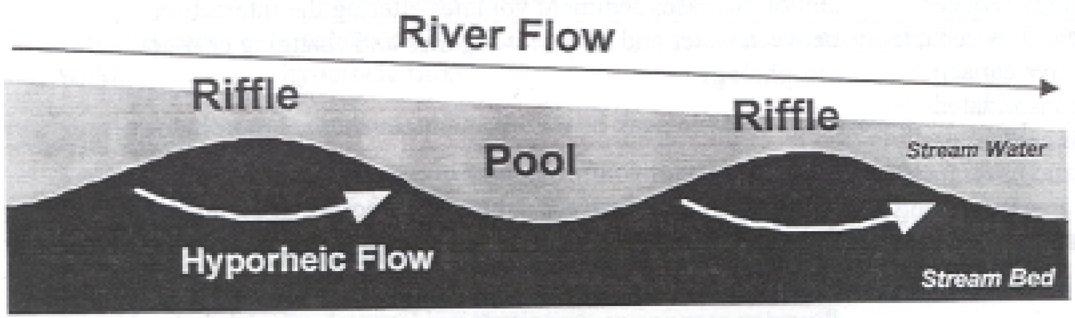
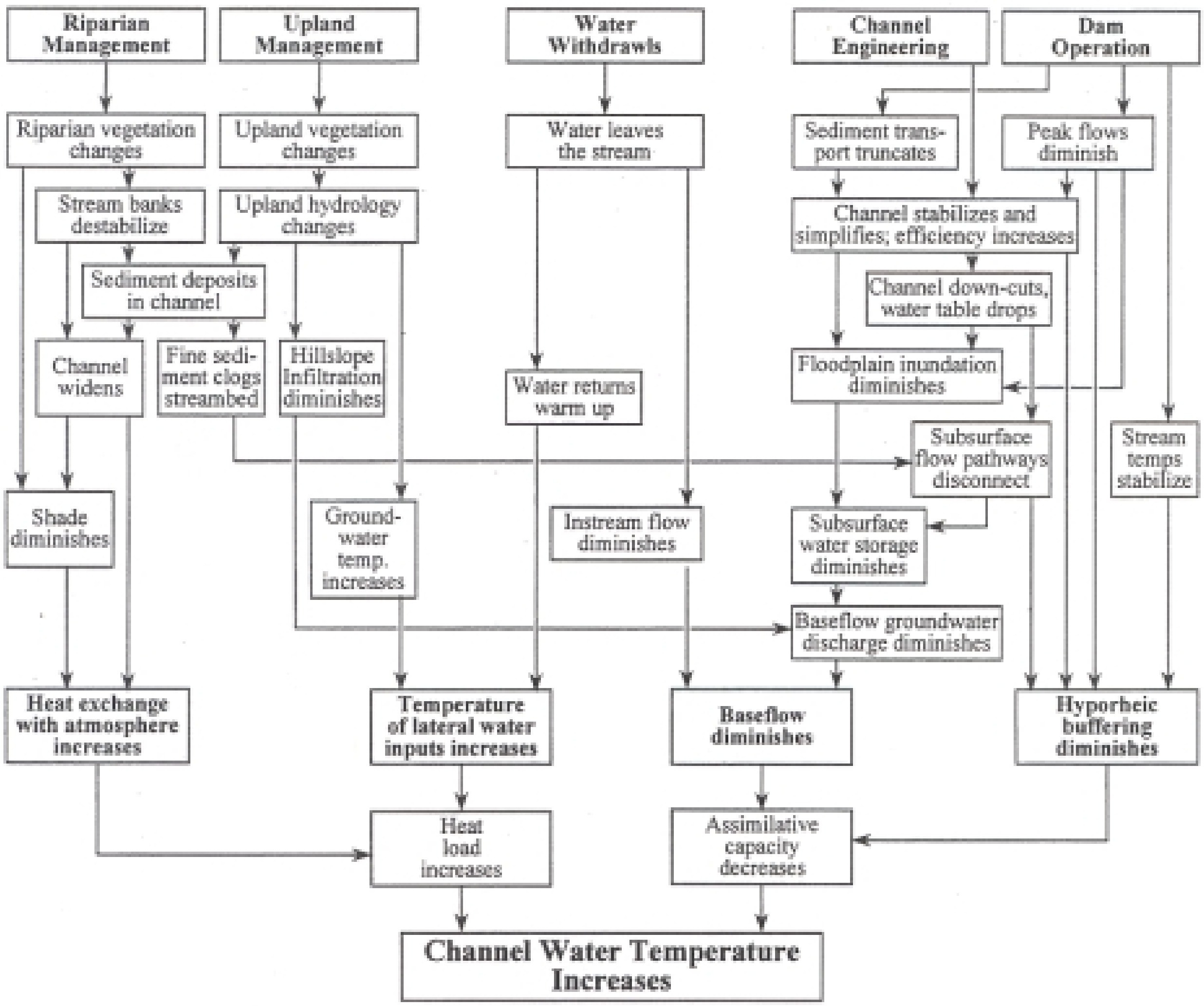


Figure 2. Downstream vertical profile of a stream showing streambed hyporheic flow in the streambed.



F igure 3. Pathways of human-caused warming of water stream channels.